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ORIGINAL ARTICLES.

I.—A Remarkable Rock Stream in East Iceland.

By Leonard Hawkes, M.Sc., F.G.S.

(PLATE VI AND TEXT-MAP.)

In his account of the volcanoes of Iceland, Thoroddsen describes two types of acid lavas which have been extruded in post-Glacial, prehistoric times. First are the lavas of the Torfajökull district, of the usual nature of acid flows, building up a compact mass of bluish-grey rock with an outer casing of obsidian and pumice. These lavas have been poured out in the post-Tertiary country, but the second type of stream is found most frequently in the older parts of the island, which otherwise have witnessed no volcanic eruptions since Tertiary times. This type of flow results from eruptions of a peculiar character in which "vast outflows of half-melted and unmelted masses of liparite, poured out from cauldron-shaped depressions, stretch down into the lowlands" (1, p. 503). The best example of these "Liparitische Blockströme" occurs in the Lodmundarfjord district, E. Iceland, and is especially described by Thoroddsen (2, pp. 159–161). In this paper the contention is put forward that the Lodmundarfjord blockstream is not a lava-flow but an unusual type of glacial moraine.

Unfortunately the magnificent topographical map of Iceland in preparation by the "Generalstaben" of Copenhagen does not yet include the Lodmundarfjord district, and no claim of special accuracy is made for the rough sketch-map of Fig. 3, which is given to render the description below more intelligible. The Lodmundarfjord, running approximately east and west, is bounded on both sides by ramparts of Tertiary plateau-basalts from two to three thousand feet in height. The fjord is continued inland in a broad flat valley, the Bárdarstadadal, and a raised beach, 23 metres high, after Thoroddsen (2, p. 103), shows that the sea formerly stretched far up the valley. The only notable breach in the southern wall occurs at 800 feet, the mouth of a broad hanging valley which forms part of the pass (the Hjalmadalsheiði, *circa* 2,000 feet) leading over to the Seydisfjord. On the north side, near the end of the fjord proper, a broad valley, the Hraundal, leads up from sea-level to the inland plateau in a north-westerly direction. The mountains of the Lodmundarfjord are built up exclusively of basalts and red tuff partings, but a thick series of acid rocks is exposed in the cliffs bordering the upper reaches of the Hraundal, being the southern extension of the largest area of

acid rocks in Iceland. Especially noteworthy is the mountain Skúmhöttur, *circa* 3,000 feet high, into which a huge cirque extends. The cirque walls are very steep, falling to a broad gravelly plain about 750 feet high, over which a river—the Hrauná—meanders in a south-easterly direction till it cuts through a rise of about 50 feet, the beginning of the blockstream, and takes a rapid course through a gorge to the fjord. The blockstream is a chaotic assemblage of large angular blocks of liparite, a great number being twelve or more feet in diameter, with an extremely uneven hummocky surface, forming a wilderness known as the "Hraun".

"Hraun" is an old Norse word meaning "a rough place", "a wilderness", but in Iceland it came to signify "a lava field when

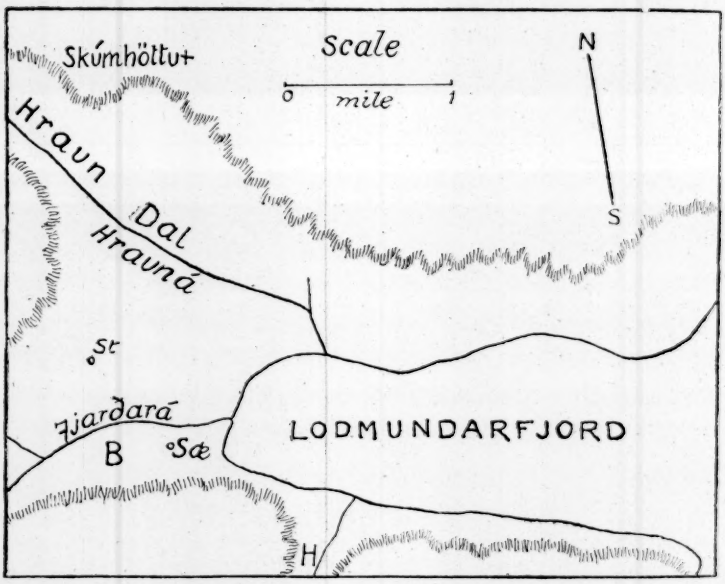

FIG. 3.—Sketch-map of the Lodmundarfjord District. H = the Hjalmadal; B = the Bárdarstadadal; Sæ = the farm Sæverendi; St = the farm Stakkahlíð.

cold", "a burnt place", being so used in the Sagas as well as in modern times (**3**). Thoroddsen regards the blockstream as a lava-flow extruded from Skúmhöttur. The rough block surfaces of some acid lavas are well known and cited as a parallel, albeit the exceptional unevenness of the "Hraun" is taken as an indication that the lava was exceptionally viscous, and the daring suggestion is made that the liparite was first intruded into the Tertiary basalts and cooled down so slowly that when the plateau was dissected by dislocation and erosion the still hot magma flowed out as a stream of half-melted blocks (**2**, p. 161). A closer examination of the district reveals little to support this hypothesis. It is clear that the greater

part of the material composing the "Hraun" comes from Skúmhöttur, but I am not satisfied that "the liparite is for the greater part intrusive here" (**2**, p. 276). The acid series is estimated to have a maximum thickness of 1,800 feet, and though the actual junction was covered with snow (June month) the basalts did not show any signs of disturbance commensurate with that to be expected if the main part of the series were intrusive. The acid rocks here are similar to those which the author has described from the neighbouring Seydisfjord (**4**, pp. 391–2), consisting of tuffs, breccias, obsidian, and liparite. One breccia underlying the main mass contains large fragments of liparite, pitchstone, and obsidian, and the farmer at Stakkahlið has some petrified tree trunks which were obtained here. Thus with proof of the extrusive nature of part of the series, and in the absence of indications of intrusion with the exception of some dykes, it seems probable that the main mass was extruded in Tertiary times, as is the case with so many occurrences of acid rocks in East Iceland (**5**, p. 468).

The chief objection to the hypothesis of a lava origin is the nature of the "Hraun" itself. Examination revealed the fact that the rock stream is not, as has been stated, exclusively composed of spherulitic liparite, but contains pitchstone, obsidian, pumice, and basalt. A beautiful mahogany obsidian is especially noteworthy, and all the rocks mentioned are to be seen in situ in the Skúmhöttur mountains. In the gorge of the Hrauná the "Hraun" is seen to be fragmental and composite to the base and to contain much gravelly material.[1] I saw no sign of a liparite dyke in the gorge, or any evidences of fumarolic action in situ as reported by Thoroddsen.

Perhaps the most interesting part of the rock stream, which is about one and a quarter miles in length, is its termination in the main fjord valley. Near the fjord the blocks become smaller until the final fan of fine fragmental material is reached, resting on the floor of the Bárdarstadadal, north of the Fjarðará. These deposits are seen in Pl. VI, Fig. 1. South of the river, at and to the west of Sæverendi, are a number of conical mounds commonly composed of liparite fragments, with obsidian and basalt less frequently. One of the largest mounds was elliptical in plan, 100 feet by 80 feet, with a maximum height of 23 feet, and contained a block of liparite 7 feet in diameter. Proceeding westwards the mounds become fewer and further between until about half a mile from Sæverendi the last one occurs close to the southern wall of the valley. Many of the mounds are exclusively formed of one type of rock, some of obsidian and others of liparite, and they furnish the clue to the problem of the origin of the "Hraun". Owing to its jointing

[1] In connexion with the lava hypothesis as advanced by Thoroddsen it is of interest to note that the block surface of some lavas in the Cordilleras of South America was taken by Humboldt and de Boussingault as evidence of eruption in fragmentary form, but Scrope considered this an "improbable hypothesis", pointing out that the fragmentary nature of lava streams is a property restricted to their upper and under surfaces, the main mass being compact (**6**, p. 70).

liparite commonly weathers out in very large blocks. A striking demonstration of this is to be found at the head of the Jafnadal, Stöðvarfjord, S.E. Iceland. The valley ends in a large cirque, the walls of which are chiefly composed of liparite. The plain about a thousand feet below the top of the cirque wall is dotted over with blocks of liparite which have rolled from above over the steep snow slopes. The largest of these blocks, measuring 90 feet by 45 feet by 40 feet, has split in two at its final resting-place (see Pl. VI, Fig. 2). The complete weathering down of such a block would give rise to a mound like the largest of those in the Lodmundarfjord valley. The mounds clearly result from the weathering of large blocks in situ, and the only agency which can be imagined to have brought them to their positions so far west is that of ice floating in the sea, which once stretched far up the valley as evidenced by the raised beach deposits. Thus the "Hraun" is of raised beach age and was not formed subsequently (**2**, p. 159), and it dates from the end of the last Ice Age, when the glacier of the fjord valley had retreated. The raised beaches along the fjords of the Folden district, Salten, N. Norway, are considered by Rekstad to be formed of morainic debris, and to date from the time when glaciers flowed down side valleys to the shores of the fjords (**7**, pp. 10–11). A similar explanation suffices for the deposits described in the Bárdarstadadal, and thus the "Hraun" is to be regarded as the moraine of a glacier flowing down Hraundal.

The morainic theory is rejected by Thoroddsen on two main grounds. These are (1) that "the whole mass of debris and blocks consist exclusively of one particular rock, spherulitic liparite, whilst a moraine must contain both", and (2) "no ice scratches are found on the blocks" (**2**, p. 160). As mentioned above, besides obsidian basalt does enter into the composition of the "Hraun", though to a remarkably small extent. This is partly understood when we consider the brittleness and fissility of liparite as contrasted with the toughness of basalt, whereby the former succumbs more easily to erosive agencies than the latter. The readiness with which liparite breaks up would itself account for the absence of ice-scratches on the blocks. During a field examination, extending over several weeks, of the acid rocks of East Iceland, the writer never saw an ice-scored surface of liparite.

I regard the "Hraun" as a surface "block-moraine", and it would not bear ice-scratches. The material probably did not fall slowly on to the glacier as a talus stream, but descended in great landslides, as has been suggested for some of the rock streams in the San Juan Mountains, Colorado, which are characterized by "the remarkable quantity of relatively coarse material comprising them, and the fact that the greater part of this must have been carried on the surface of the ice" (**8**, p. 25). The "Hraun" presents many analogies to the rock streams of the San Juan Mountains. These latter are comparable in size, the hummocky surface is similar, they are often composed of Tertiary acid volcanic rocks, and the topography of the district is that of a "dissected and glaciated plateau of more or less horizontally bedded volcanic rocks" (**9**, p. 11).

An interesting case of a landslide on to a glacier, which illustrates what has probably taken place in the formation of the "Hraun", is recorded by Freshfield from the Caucasus. "The Shikildi Glacier presented itself as an advancing mound of huge blocks of grey granite. . . . In 1866 a noise as of thunder was heard by the shepherds of the Baksan, and a great cloud of smoke or dust was observed to issue from the recesses of the chain under Ushba. . . . After a time it was ascertained that a great rock had crashed down from the cliffs on the east side of the Shikildi Glacier. . . . We saw next day the gap in the mountain side which had provided the enormous masses now strewn over the lower glacier. . . . I never saw such a goods-train of a glacier. . . . The immense size of the single blocks and the complete burial of the ice under them are the features which give their extraordinary character to the moraines of the Shikildi" (**10**, pp. 137–8). It is interesting to note that in the Saga relating the colonization of the Lodmundarfjord, *circa* 900 A.D., mention is made of a landslide, and whilst this cannot refer to the main mass of the "Hraun", there is little doubt that we here have evidence that sliding has taken place in historic times.[1]

Many of the San Juan rock streams are regarded as landslides which had no connexion with glaciers. It would be possible to regard the "Hraun" as such, and the mounds in the Bárdarstadadal as being formed from blocks transported by the shore ice-foot when this broke up. But apart from the fact that the general aspect of the "Hraun" is rather that of a moraine than a landslide, it is very probable that under the severer climatic conditions giving rise to an ice-foot, a glacier would exist in the Hraundal. Strictly the term "moraine" should be used only of material which has been actually transported by a glacier, rock debris which falls on to a stationary or retreating glacier being termed ordinary talus accumulations or landslide material according to degree. There will be cases which stand near the border-line between these two classes which will only be correctly placed after very careful investigation. Whilst reserving a final decision until the writer can make a more thorough examination, he is inclined to the opinion that the "Hraun" has been transported to some extent by a glacier and is therefore a true glacial moraine.

The rejection of the "lava-flow" hypothesis removes an exception to an important generalization, i.e. the post-Glacial instances of volcanic activity in Iceland are confined to the Quaternary Formation districts, so that the post-Glacial vulcanism is to be regarded as the direct continuation of the Quaternary and not the Tertiary activity (**12**, p. 18). It may be considered remarkable that the same

[1] "Lodmund the Old was the name of a man, and another was Beowolf his sworn brother. They came to Iceland from Thule-ness in Vors. Lodmund cast his porch-pillars overboard while he was at sea, and said that he would settle where they were drifted ashore. And the sworn-brethren made East-frith, and Lodmund took in settlement Lodmund-frith, and dwelt there three winters. Then he heard of his porch-pillars being in the south of the country. And with that he put on board his ship all that he had. . . . And when he had been a little while, there was a great rumbling noise, and they saw a great earth-slip fall upon the homestead which Lodmund had set up and dwelt in."—*Landnámabóc*, iv. 9 (**11**).

rock-stream should be regarded by one observer as a lava-flow and by another a glacial moraine, but a similar case is on record in the history of Icelandic geology. An accumulation of liparite blocks and debris in the Vatnsdal, Húnafjord, North Iceland, was thought by Schmidt to result from a post-glacial volcanic eruption (**13**, pp. 764–5), but it is now considered to date from the end of the Ice Age and to represent a great fall of rock on to a glacier (**2**, p. 271).

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EXPLANATION OF PLATE VI.

FIG. 1.—General view of the Lodmundarfjord "Hraun", looking north from Sæverendi. The Skúmhöttur cirque is seen in the middle background. The main fjord valley and the "Hraun" deposits north of the River Fjarðará occupy the foreground.

FIG. 2.—A great fallen block of liparite, now split into two, in the Jafnadal, Stöðvarfjord, East Iceland. A hammer may be distinguished on the face of the nearer block, not far from its base.

II.—ON THE JURASSIC FOSSIL FUNGUS, *PHYCOMYCITES FRODINGHAMII* (ELLIS).

By DAVID ELLIS, Ph.D., D.Sc.

(WITH PLATE VII AND A TEXT-FIGURE.)

IN a recent paper[1] the writer described structures which he had found in the Frodingham Ironstone of Lincolnshire. The claim that these structures are fossil fungi is one of more than usual interest, for fossil fungi have not hitherto been recorded from the Jurassic rocks, and, further, the decomposition established by this fungus must have been carried out under marine conditions. Since the publication of this paper criticisms as to the conclusions contained in it have not been wanting, and it is proposed in the present paper to deal with these criticisms and further to furnish a few additional data to supplement those that have already been given.

[1] "Fossil Micro-organisms from the Jurassic and Cretaceous Rocks of Great Britain": Proc. Roy. Soc. Edinburgh, vol. xxxv, pt. i, No. 10, 1915.

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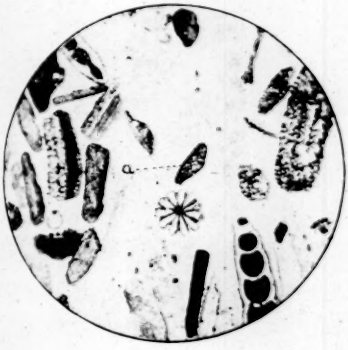

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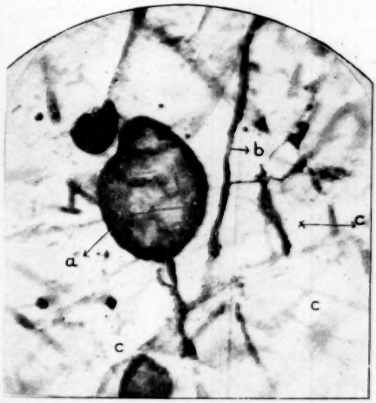

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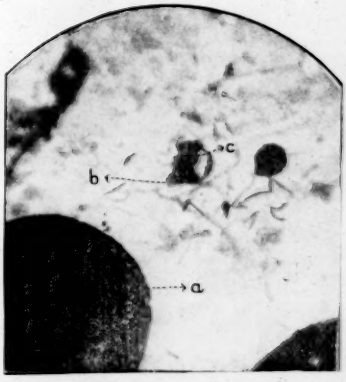

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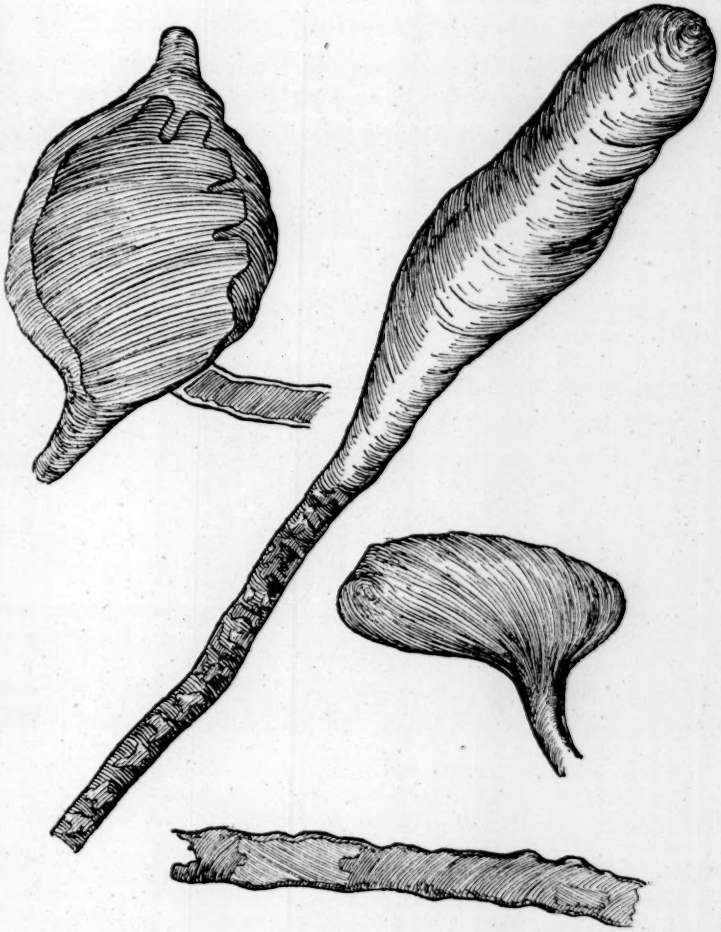
A JURASSIC FOSSIL FUNGUS.

Phycomycites Frodinghamii, &c.

Before dealing with the criticisms it must be borne in mind that the conclusions arrived at in the former paper were based on biological grounds. The structures were such as a biologist recognizes to be characteristic of fungi. They take the form of tubes coated with ferric oxide and conform to fungal structures in the following respects:—



Sketch of animal remains in Dunliath Ferruginous Limestone (Jurassic), N.W. Scotland, found in association with fungal hyphæ. × 1400.

1. The tubes are cylindrical and possess a membrane comparable to the membranes of modern fungi.
2. The diameter of the tubes is 2 μ to 4 μ ($\frac{1}{5000}$ — $\frac{1}{2500}$ mm.).
3. They branch and interweave in the manner characteristic of modern fungi. (In addition they also form whorled branches:

whilst not characteristic of modern fungi this feature is characteristic of other plants.)

4. They are uniform in size.

5. They form terminal dilatations which are comparable to the sporangia of modern fungi. This is particularly so with regard to their size as compared with the tubes which bear them, to their shape, and to their terminal position. In all respects they suggest the development of terminal reproductive organs on hyphæ (Pl. VII, Fig. 1).

6. In two instances, one of which is shown in Pl. VII, Fig. 2, rounded structures have been noted inside the terminal dilatations which in every essential particular suggest the spores which are formed inside the sporangia of modern fungi.

7. The structures in question are found in an organically formed rock (Pl. VII, Fig. 3).

The circumstantial evidence upon which alone the whole case naturally rests seems thus, from a biological standpoint, to be complete enough to allow of little doubt as to the matter. The points with which we shall now be dealing have had their inspiration in the minds of those accustomed to regard such matters more from the geological and mineralogical than from the biological standpoint.

1. *The structures in question may be of mineral and not of organic origin.*—Throughout the history of this subject mineral secretions have been repeatedly mistaken for organic remains. So far as the imitation of plant organs is concerned the structures imitated are leaves and cellular tissues. But from the nature of the case the plant patterns executed by these secretions are of a simple form and their variety of a very limited order. Whilst such secretions may imitate a cellular or a tubular structure, it is difficult to see how the whole atmosphere in which a phycomycetous fungus lives can be simulated so very faithfully by a mineral secretion that not only are hyphæ and hyphal membranes reproduced but also sporangia (Pl. VII, Fig. 1) and even spores (Pl. VII, Fig. 2). Further, the relative dimensional proportions of the parts are so faithfully adhered to that even when examined with the highest powers of the microscope, a trained eye cannot detect any details of structure inconsistent with the structural plan of phycomycetous fungi. Such wonderful fidelity in detail would demand strong evidence of an opposing nature to dismiss the claim that the structures in question are fossilized fungal remains. The slides have been submitted to several competent mineralogists for their opinion of the structures from the mineralogical standpoint. In no single case was evidence forthcoming to suggest that a mineral interpretation of these tubes and expansions would fit the facts of the case. Among those to whom the slides were submitted was Dr. Flett, of the Geological Survey, Edinburgh, whose opinion on this point will command respect. Dr. Flett stated that he was prepared to accept the organic origin of the structures indicated to him and that he knew of nothing in the mineralogical world that approximated to them. From the mineralogical standpoint no single positive fact has been brought to light which invalidates the claim for organic origin made from a study of the biological data.

2. *The structures may have been caused by insect borings.*—If the causation of these threads and vesicles is not to be ascribed to a mineral infiltration, and an organic origin is granted, there still remains another possible origin, viz. that the tubes were due to insect borings. This possibility has been suggested to account for the tubes and vesicles. This criticism would have weight were it not for the extreme smallness of the tubes. These measure only $\frac{1}{125}$ mm. In previous cases where this criticism had weight, as for example in the case of the *Rhizomorpha Sigillarieæ* of Lesquereux, the tubes under consideration were 2–3 mm. in diameter, and the claim was made that they were rhizomorphal cords of fungal hyphæ. Being commensurate in size with known insect borings, the criticism that they might have been produced by insects was quite legitimate. We are here, however, dealing not with cords of hyphæ, but rather with the individual strands such as are commonly found in the woody tissues of many plants. The possibility of their preservation need not be discussed, as their appearance in the tissues of fossil wood is too common and too well known to admit of any doubt on the matter. It is not conceivable that any insect either during Mesozoic times or at any time could make borings which simulated the biological characteristics of a fungus on such a minute scale. It is the more incredible when we reflect that these supposititious borings would be excavated in the body of some animal fragment, the natural habitat of many phycomycetous fungi, and not in the harder tissues of trees in which insect borings are usually found.

3. *Criticisms arising from the fact that whilst the parasite (or saprophyte) has been preserved the details of structure of the host in which it lived have not been preserved.*—In answer it may be stated that the discovery of this organism was not entirely due to an accidental circumstance, but was rather the successful issue of a specific search. In the author's researches on modern iron-bacteria, the membranes of which are impregnated with the highly resistant ferric oxide, he was led to the conclusion that if iron-bacteria or their representatives existed in former ages the chances of their preservation in fossil form were very strong. When the opportunity occurred ironstones and ferruginous limestones of various ages were carefully searched for iron-absorbing micro-organisms. The toughness and hardness of such membranes can be observed by anyone who cares to examine the dead membranes of the modern ochre-bacillus (*Leptothrix ochracea*). The search did not reveal fossil iron-bacteria as was expected, but it did bring to light a fungus possessing the same characteristic of absorbing iron-compounds from the surrounding water. An organism thus protected would obviously stand a much better chance of preservation than the soft tissues of the animal fragments inside which a fungus of this character must necessarily abide. The slides containing these structures consist of fragments of organic matter embedded in a calcite matrix (Pl. VII, Fig. 3). The threads and vesicles were invariably found inside the organic fragments and not in the matrix. An example is shown at *a* in Pl. VII, Fig. 3. This fragment is seen photographed on a higher scale of magnification in Pl. VII, Fig. 4. In the latter case the threads

under discussion are plainly revealed. It cannot be reasonably doubted that the fragment marked *a* in Pl. VII, Fig. 3, is an organic fragment similar to the other obviously organic fragments that are to be seen in the same field. It is unfortunate that in the Frodingham Ironstone in which these were found no traces of the internal structure of the animal host could be discerned, whilst the details of the structure of the parasite contained in it were so clear. This point, however, is capable of an easy explanation if it be assumed that the threads and vesicles represent a fossil fungus which *during its lifetime* had the same power of absorbing iron salts that the iron-bacteria possess at the present day. Under these circumstances the membranes of the fungus would be impregnated with ferric oxide during its lifetime, a circumstance which would render these membranes much more resistant to disrupting forces than the soft tissues in which they were embedded. Further, it is possible to conclude with a fair approach to certainty that the iron on the threads was laid down for the greater part during their lifetime. The reason for this conclusion is as follows: A study of the iron-bacteria has brought to light the fact that the deposit of iron on their membranes varies in consistency according to the age of the thread. Young threads have a sharply contoured membrane of a brownish-yellow colour. In older threads the nature of the deposition and of the membrane is quite different. The colour of the iron changes to a deeper brown, the quantity of it is greater, and the membrane, instead of being a continuous sharply outlined structure, is a discontinuous irregular line and wanting in sharp lines of demarcation. All gradations can be observed by a close study of the membranes of *Leptothrix ochracea*, the best known of the iron-bacteria. It is surely a significant fact that the same gradations can be observed on the membranes of the threads which we are now discussing. The appearance of these gradations is easily explicable if we assume that the tubes are the remains of an iron-absorbing fungus, but on the assumption that all the iron in these rocks, including the iron on these tubes, resulted from a subsequent infiltration of iron-charged water, the explanation is not so easy. It cannot be doubted that the bulk of the iron in these rocks arrived there by subsequent infiltration, but it is at least highly probable that some of it has never been absent from the material from which these rocks were formed. If the iron on these tubes had got there solely by infiltration, it would naturally be expected that all the tubes would have a deposit of a uniform nature; the tubes, on the other hand, show those changes which come about when iron enters the living cell, and after undergoing changes due to metabolism is thrust out again and deposited on the outer part of the membrane.

We may assume that the presence of the iron covering is a sufficient explanation of the preservation of these threads and vesicles. Whilst a search among the organic particles of the Frodingham Ironstone containing the fungus failed to reveal traces of the structure of the host, a measure of success was achieved by searching the similar Jurassic ferruginous limestone at Dunliath in the north-west of Scotland. In Pl. VII, Fig. 6, for example, we see an organic

fragment showing traces of animal cells (*a*), and also a few hyphæ of some unknown fungus (*b*). Again, in others inside similar organic fragments structures like those represented in the Text-figure and in Pl. VII, Fig. 5 were met with. These are obviously the remains of some animal cells, although in this condition it is impossible to specify any further with regard to their nature. The point of the matter lies in this, that these organic fragments from Dunliath contain the remains of both animal cells and fungal threads, both very incomplete and very indefinite: in the Frodingham Ironstone the disruption of the animal cells has been complete, whilst the fungus, thanks to its protective covering, has been particularly well preserved.

4. *Doubts arising from the fact that the threads and vesicles were found in material known to have suffered decomposition in sea-water.*—Whilst it is true that no fossil fungi have so far been found of which it could be definitely stated that they had effected decomposition in salt water, the reason for this does not lie in the fact that there is anything inherently impossible in the idea, for that would imply that decomposition of organic matter cannot take place in salt water, which is contrary to experience. It is true that the vast bulk of marine decomposition is due to the activity of bacteria, but even in this field a large proportion of the organisms which carry on this decomposition belong to the sulphur bacteria, several species of which group are composed of long threads, thus approximating in their habits to the threads of which the aquatic fungi are composed. In the artificial cultivation of many of the thread-forming sulphur bacteria success attends the attempt only if sea water instead of fresh water be employed. A still more powerful argument is the fact that in the cultivation of some of the Saprolegnias, a group of phycomycetous fungi, the use of sea water is recommended in making up the nutrient medium. So that even in the case of modern plants of the same group we meet with fungal decomposition under marine conditions. Anyone who has studied the shores of Denmark can satisfy himself of the extent to which marine decomposition can operate in the scavenger work of Nature. The shallow Jurassic seas must have had huge shallow lagoons in which of necessity scavenger work on a large scale must have been in operation. It would be an extremely rash statement to assert even apart from our experience of modern fungi that no thread fungi could have contributed to this work. For even if such fungi did not exist at the present day, there are so many closely allied forms that effect decomposition in salt water that marine fungi in a fossil form would not have been a matter for surprise.

Conclusion.—The study of the tubes and vesicles classed under *Phycomycites Frodinghamii* had revealed their organic nature by the closeness with which their structures followed those of modern fungi. The resemblances extended even to minute points of structure, and were so great that from a biological standpoint no doubts were entertained as to the fact that we were dealing with fossil fungi allied to the modern Phycomycetes. It remained to inquire whether any positive evidence could be adduced, or any facts brought forward on

mineralogical or geological grounds, which could impair the position taken up. The criticisms on theoretical grounds which have been brought forward have not invalidated the claim for these structures which the writer has brought forward. It is proposed to present the slides to the British Museum, so that they can be made available for inspection and reference.

EXPLANATION OF PLATE VII.

FIG. 1.—Frodingham Ironstone from Jurassic rocks of Lincolnshire. From interior of fossilized organic fragment. Shows hyphæ, one bearing a fully developed terminal sporangium. *a* = sporangium, *b* = hypha. *c* = calcite matrix. × 530.

,, 2.—Frodingham Ironstone from Jurassic rocks of Lincolnshire. Shows two sporangia of *Phycomycites Frodinghamii*. In the left sporangium (*c*), partially extruded from it, is seen a spore (*b*). *a* is a portion of a small oolite. × 166.

,, 3.—Organic remains in Frodingham Ironstone. At *a* is shown a fragment in which fungal hyphæ were found. × 18.

,, 4.—The organic fragment marked *a* in Fig. 3 shown on a larger scale. The fungal hyphæ are distinctly visible. × 116.

,, 5.—From Dunliath Ferruginous Limestone (Jurassic, N.W. Scotland). Remains of animal cells. × 466.

,, 6.—A semi-diagrammatic sketch of a portion of an organic fragment in the Dunliath Ferruginous Limestone. Inside the fragment are seen the remains of animal cells and of fungal hyphæ. The branched tubules are the hyphæ and the dark rounded fragment the animal cells.

III.—On the Organization of the Rugose Corals and the Origin of their Characteristic Peculiarities.

By Professor N. N. Yakovlev, Petrograd, Russia.

(PLATE VIII AND FOUR TEXT-FIGURES.)

DURING the last ten years I have published a series of memoirs[1] on different questions concerning the morphology and biology of the Rugose Corals. In these memoirs I have elucidated the ground-form of the polyparium of the solitary Rugosa, the mode of its attachment to the substratum, the origin of the characteristic arrangement of the septa, and the origin of the fossulæ in dependence on this form and attachment. I have established the connexion between the form of the polyparium of the Rugosa (including that of the fossulæ) and the life of these corals in definite environmental conditions.

[1] N. Yakovlev, "Die Fauna der oberen Abtheilung der palaeozoischen Ablagerungen im Donetz-Bassin. II. Die Korallen": Mém. Com. géol. St. Petersbourg, N.S., livraison xii, 1903. "A contribution to the Characteristic of Corals of the group Rugosa": Ann. Mag. Nat. Hist., ser. VII, vol. xiii, pp. 114–17, 1904. "Ueber die Morphologie und Morphogenie der Rugosa": Ver. Russ-k. Min. Ges. St. Petersbourg, vol. xli, pp. 394–415, 1904. "Die Entstehung der charakteristischen Eigentümlichkeiten der Korallen Rugosa": Mém. Com. géol. St. Petersbourg, N.S., livraison lxvi, 1910. "Les récifs coralliens existent-ils dans le paléozoique?": Bull. Com. géol. St. Petersbourg, vol. xxx, No. 10, pp. 847–57, 1911. "Studien über die Korallen Rugosa": Mém. Com. géol. St. Petersbourg, N.S., livraison xcvi, 1914.

Referring to the colonial Rugosa, I have explained how the characteristic forms of the colonies are correlated with the mode of multiplication, and demonstrated the part played by these corals in reef-building. Here and there I have pointed out differences between the Rugosa and the Hexacoralla, which do not admit the former to be considered as the progenitors of the latter, though this is probably claimed by the majority of palæontologists and zoologists.

This examination (pursued by me for many years) of the form and functions of the Rugose Corals and of the questions they raise, I now look upon as sufficiently complete to render desirable a review of the results of my work, which throws fresh light on the Rugosa as well as providing a causal explanation of the origin of the peculiarities of this specialized group. In conformity with the character of the present paper, the exposition will be given concisely, without citations and references, without criticism of other authors, without any details; those who are interested will find all this in my previous publications.

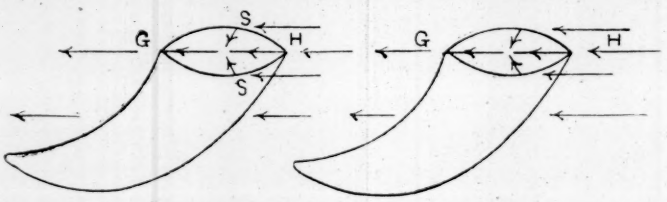
The shape of the Rugose polyparium is considered to be typically conical. Herein the Rugosa differ from the Hexacoralla, which mostly have a cylindrical polyparium; and this difference of body-form may be seen in the soft-bodied Actiniæ now living. The Rugosa are first found in Silurian rocks, but doubtless existed previous to this, and before Silurian times the Rugose polyparium had already departed from the fundamental simply-conical shape. *It had acquired*, near its proximal end, *a lateral attachment to the substratum*, unlike the basal attachment of the Hexacoralla (see Pl. VIII, Figs. 1–4). *This lateral attachment was correlated with their life in epicontinental seas.* The basal attachment of the cylindrical (or, in rare cases, conical) polyparium of the Hexacoralla living in deeper, calm water, as much satisfies the requirements of solidity as the lateral attachment of the Rugose conical polyparium living in a zone of the sea characterized by comparatively rough or at least agitated water.

The lateral attachment, then, of the Rugose polyparium is an adaptation to definite environmental conditions. It has modified the original form of the simply-conical polyparium and has imposed upon it a definite orientation correlated with the direction of the prevailing currents. For a conical polyparium lying on one side on the sea-bottom must of necessity turn away its mouth from the mud of the sea-bottom in order to avoid suffocation. Thus the simple cone with a straight axis becomes one with its axis curved in one plane—a form resembling the horn of an ox, and suggesting such trivial names as *cornu*, *corniculum*, *cornucopiæ*, *cornu-bovis*, *ceratites*, *buceros*, etc. Moreover, all the individuals of one locality were orientated in the same direction, namely, with their convex sides towards the direction of the prevailing current (see Text-fig. 1). Only thus will a polyparium of such a shape offer the maximum resistance to wave- and current-action tending to tear it from the substratum.

Now the scar formed by the attachment of the polyparium to the substratum as well as the root-like processes serving the same purpose necessarily occur as a rule on the convex side of the corallum.

And in this respect, as well as in its general form, the coral already shows an external bilateral symmetry. Scars of attachment and root-like processes, both on the convex side, and a general external bilateral symmetry, characterize all the known Rugosa from the Silurian rocks, the earliest in which they have yet been found, to the Permian in which the last Rugosa occur. Further, when, owing to the character of the sea-bottom, there is no possibility of attachment and the coral consequently is free, the polyparium, whether of a Rugose or Hexa-coral, takes on a flat, discoid shape (*Palæocyclus*, *Microcyclus*, etc.). But, in spite of its not leaning over, the Rugose Coral retains its bilateral symmetry, shown externally chiefly by the apex which lies excentrically, while that of the Hexacoral is central. That is to say, in spite of the removal of the conditions producing bilateral symmetry, the discoid Rugose Coral exhibits it. Is not this an example of the inheritance of acquired characters?

Another form showing the tendency to retain bilateral symmetry after the conditions which caused it have been removed is that taken by unattached genera such as *Calceola*, *Platyphyllum*, and other operculate corals. These are curved, flat on the lower side, and



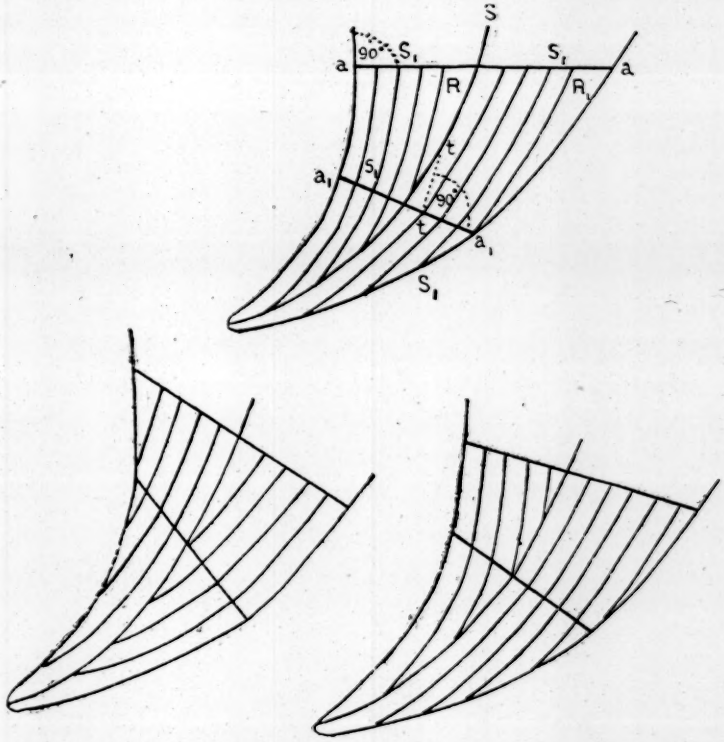
TEXT-FIG. 1.—Diagram representing two polyparia of solitary Rugosa growing side by side. The arrows outside the polyparia indicate the direction of the prevailing current, and those within the calices that of the water along the channels formed by the fossulæ. *H*, *G*, *S*, the positions of the Main, Counter, and Alar fossulæ respectively. Nat. size.

provided with an operculum whose function is to prevent the penetration of mud into the coral's calice. Operculate corals are probably polyphyletic in origin, and, as would be expected, occur only among the Rugosa.

The last external character dealt with is the frequently occurring phenomenon of "Rejuvenescence". The term is inappropriate, since young individuals also are subject to it. Rejuvenescence consists of a periodically repeated retraction of the calice as if by shrinking or by the appearance of a daughter coral produced by intracalicinal budding. Rejuvenescence, especially in the broadly conical forms, is easily explicable, in fact only to be expected, when it is considered how inconvenient and disadvantageous from a mechanical point of view a considerable upward expansion of the polyparium would be to the Rugosa with their typically conical polyparium.

Turning from the external to the internal characters of the Rugose skeleton, we shall find that they are determined by the curved condition of the conical polyparium. We shall consider, first of all, the characteristic arrangement of the secondary septa and their

relation to the primary septa—a condition peculiar to the Rugosa. The works of Duerden, Carruthers, and others have shown that the secondary septa develop in four adjoining (and in four only out of six) primary interseptal chambers, and are bilaterally symmetrical in their arrangement. Two of the primary septa lie in the plane of bilateral symmetry of the coral. About one of these—the Main-septum—the secondary septa (as seen at their outcrops on the wall



TEXT-FIG. 2.—Diagram showing the arrangement of the outcrops of the septa on the surface of the polyparium, according to whether the mouth is at right angles to the concave side (above), to the convex side (below, on the left), or to neither (below, on the right). The mouth is always at right angles or nearly at right angles to the Counter-septum. *S*, Alar-septum. *aa*, *a'a'*, the edges of the polyparium at different periods of its growth. (After Yakovlev, 1904.)

of the polyparium) are arranged pinnately; while on each side of the other—the Counter-septum—the secondary septa lie parallel both to it and to each other (see Text-fig. 2). Two other primary septa—the Alar-septa—lie somewhat at right angles to the Main- and Counter-septa, thus dividing the calice into four quadrants, two Main- and two Counter-quadrants. As seen at their outcrop on the

wall of the polyparium, the secondary septa are pinnately arranged with regard to the Alar-septa in the Counter-quadrants and lie parallel to the Alar-septa in the Main-quadrants (see Text-fig. 2 above).

Such an arrangement of the secondary septa appears to be the natural outcome of the mechanical conditions imposed by the curved state of the conical polyparium. For the mouth of the conical polyparium is generally in a plane perpendicular to its concave side (Text-fig. 2 above); and the secondary septa have a tendency to grow (as in all Anthozoa) in a plane perpendicular to that of the mouth of the calice. Since the primary septa are already existent in a curved polyparium, the secondary septa can grow in a manner just stated, and unimpeded, in two only of the four Primary quadrants, namely in the two Counter-quadrants. In the two other quadrants, namely the Main-quadrants, the secondary septa cannot grow in a plane perpendicular to that of the mouth, because, at least in part, they would be impeded by the convex surface of the Alar-septa (see the dotted line *t-t* in Text-fig. 2 above). Therefore they grow, as may be observed, so that their outcrops on the coral-wall are parallel with those of the Alar-septa.

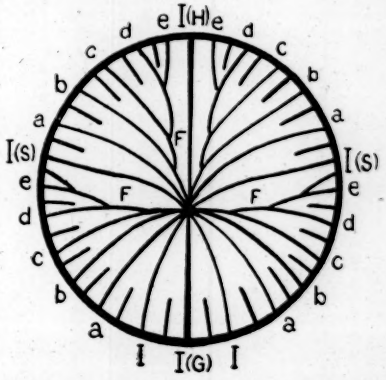
But the Main-septum, sometimes, though comparatively rarely, lies on the *concave* side of the coral. When this is so, the plane of the mouth of the calice is perpendicular to the *convex* side of the coral (see Text-fig. 2, below and on the left). Applying to this case the principle that the secondary septa tend to lie at right angles to the plane of the mouth, we see that they can only thus grow unimpeded in the quadrants lying on the *convex* side of the coral (now the Counter-quadrants), whilst in the other pair of quadrants the growth of secondary septa perpendicular to the plane of the mouth would be impeded by the concave face of the Alar-septa.

A third, intermediary type also occurs (Text-fig. 2, below and right-hand side) in which the plane of the mouth is inclined approximately equally to the convex and concave side of the polyparium. In this case the Main-septum occurs on the convex side of the coral as it did in the first instance.

The fossulæ arise as a necessary consequence of the primate arrangement of the secondary septa. For there is always a comparatively broad space left between the youngest secondary septa and the Main-septum in the two Main-quadrants, and between the youngest secondary septa and the Alar-septa in the Counter-quadrants (R, R_1 of Text-fig. 2 on the left) into which the soft tissues settle down and contribute to the widening of these spaces, converting them into permanent cavities. These spaces are the Main- and the Alar-fossulæ. The Main-fossula placed on the convex or concave side of the corallum, according to the position of the Main-septum, is really two juxtaposed fossulæ, but appears as one, because of the shortness of the Main-septum. Consequently it is wider than the Alar-fossulæ and is more constantly conspicuous than these. The shortness of the Main-septum is caused by the soft tissues settling down into the Main-fossula. This sagging of the soft tissue, pressing also against the sides of the fossula, caused

the deviation of the free edge of the secondary septa towards the one preceding it, so as, finally, to fuse with it (*a* with S_1 and *I*, and *b* with *a*, in Text-fig. 3), giving the appearance (it is, of course, only an appearance) of repeated branching of the primary septa. The septal fusion occurs in young individuals as well as in mature ones. The older parts of many polyparia become cylindrical and straight instead of conical and curved. In these there are no wide spaces between the primary and secondary septa, and consequently there is less development of the fossulæ, and the fusion of the septa disappears—in a word, radial symmetry, doubtless existent in the progenitors of the Rugosa, is re-established.

Since the fourth fossula, that lying on each side of the Counter-septum, is rarely visible in the Rugose skeleton, its origin must be different from that of the other fossulæ. Its presence is due to the fact that there are no secondary septa adjacent to the Counter-septum. A study of the functions of the other fossulæ (of course

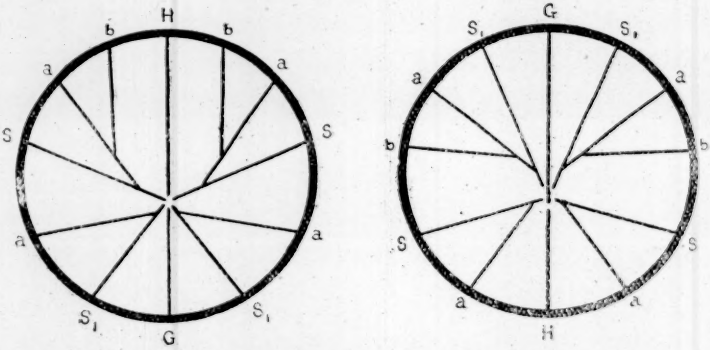


TEXT-FIG. 3. — Diagram of the calice of *Hadrophyllum pauciradiatum*, Edwards & Haime. *H*, *G*, *S*, Main, Counter, and Alar septa respectively. *a*–*e*, secondary septa. *F*, *F*, *F*, Fossulæ. (After Duerden, 1905.) Nat. size.

a purely hypothetical consideration, dealing, as it does, with the soft parts of an extinct group of animals) may help to explain the origin of the Counter-fossula. It appears to me that the function of the Main- and Alar-fossulæ was to bring water to the axial part of the coral. This is partly corroborated by the fact that all three lie in one general direction, since the Alar-septa make an acute angle with the Main-septum. I have established the hypothesis that the solitary, curved polyparia of the Rugosa, during their life, were orientated on the sea-bottom with their convex sides towards the prevailing currents, a position most advantageous from a mechanical point of view (see Text-fig. 1). This orientation itself would cause the water to flow along the Main- and Alar-fossulæ towards the axial parts of the coral; and the water would naturally find its exit on the opposite side, namely along the Counter-fossula, which doubtless arose for this purpose. For, though not constantly expressed in the

skeleton, the Counter-fossula would then be too important not to be constantly expressed in the soft parts of the coral. If this were so, the presence of the Counter-fossula in the soft tissues might actually impede the formation of secondary septa in the loculi adjacent to the Counter-septum (Text-fig. 4).

A last peculiarity of the solitary Rugosa correlated with the curved, conical polyparium, is the fact that the number of secondary septa present in the quadrants on the convex side, is sometimes greater than the number of secondary septa on the concave side (Text-fig. 4). Consequently, the position of the axis of the coral, as defined by the point of meeting of the primary septa within the polyparium, appears displaced towards the polyparium's concave side. This phenomenon is no doubt due to retardation of development on the concave side, as though under the influence of contraction of the coral here at its curved part; on the convex side, on the other



TEXT-FIG. 4.—Diagrammatic sections of *Lophophyllum proliferum*, McChesney. The section on the left is a Russian and on the right an American specimen. In both cases the upper side of the section is on the convex side of the polyparium (after Yakovlev & Duerden, 1903). *H*, *G*, *S*, Main, Counter, and Alar septa respectively. S_1, the fourth pair of primary septa. *a*, *b*, secondary septa. $\frac{3}{4}$ nat. size.

hand, the development is accelerated, as though under the influence of distention.

Colonial Rugosa are characterized by intracalicinal budding, resulting in a bush-like appearance, and causing a limited growth of the colony. Hexacorals, on the other hand, multiply by division and build colonies which spread far from their initial point on the surface of the substratum. Colonial Rugosa also differ from Hexacorals in the greater size of their individual corallites. The Rugosa, consequently, do not possess the plasticity necessary for producing the variety of colonial forms that we find among the Hexacorals, e.g. *Madrepora*. To the small dimensions of the colonies and to the monotony of form probably was due the small share they took in building Palæozoic reefs.

The Rugosa became extinct at the close of Palæozoic time, probably in consequence of an unfavourable environment, which may have

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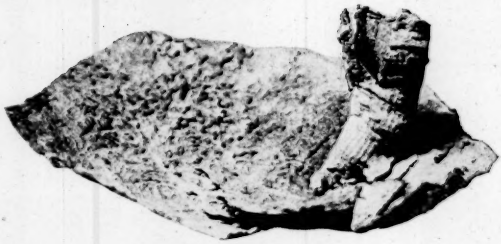

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LATERAL ATTACHMENT OF RUGOSE CORALS.

been due to the following causes. The end of Palæozoic time coincides with a worldwide period of mountain-building—the period of the so-called Appalachian revolution of American authors, and that of the building of the Ural and Donetz ranges of Russia (where the change of facies is surprisingly abrupt—the limestone strata of the Upper Carboniferous giving way to the Permo-Carboniferous characterized by great expanses of sandstones). When the limestones, laid down in shallow and comparatively calm waters, were deposited, the environment was favourable to the life of Rugosa Corals. But the mountain-building uplifts, causing great quantities of clastic material removed by denudation to be brought down and deposited in the sea, created conditions the reverse of favourable to the corals. In the Permo-Carboniferous the Rugosa are already rare, and after that time are extinct; and nearly the same fate befel the Tabulate corals. When suitable conditions again arrived, a new race of corals arose—the Hexacorals—replacing the Rugosa.

The above explanation of the organization of the Rugose Corals results from considering the simple primary factors of morphogenesis. I think that it is only for such simply organized animals as the Cœlenterata that such a complete and harmonious explanation is possible; and that it is not possible to give an all-embracing expression, reduced to a mathematical formula, of the structure of higher animals, because of their complex organization. In a few cases, however, such expressions have been found for isolated organs of higher animals; for instance, in the case of the development of the feet and teeth of Vertebrates.

EXPLANATION OF PLATE VIII.

The Lateral Attachment of Rugose Corals.

Fig. 1.—*Cyathophyllum ceratites*, Goldfuss, attached to a branch of *C. cæspitosum*, Goldfuss. Devonian: Timan Range, River Uchta.

,, 2.—*Pseudocaninia conica* (Fischer de Waldheim), attached to a spine of *Archæocidaris*. Upper Carboniferous: Mjatshkovo village, Government of Moscow.

,, 3.—*Petraia permiana*, Nechaev, attached to the dorsal valve of *Strophalosia*. Permian: Gorodistshe village, Government of Vjatka. A. V. Nechaev's specimen.

,, 4.—*Cyathophyllum heterophyllum*, Edwards & Haime, attached by a highly developed, sole-like appendage. Devonian: Paffrath, Rhenish Prussia.

IV.—A Mineralogical Classification of Igneous Rocks.

By Arthur Holmes, A.R.C.S., D.I.C., B.Sc., F.G.S.

DURING the past two years the teaching collection of rocks in the Geological Department of the Imperial College has been under re-arrangement, and in the course of the work the writer has had occasion to consider very carefully the principles on which igneous rocks should be classified. He is aware that in the present state of our knowledge any such classification must be tentative and experimental, and should be judged according to its general convenience, both for teaching purposes and for understanding the various problems that arise from petrological studies. The following article summarizes

the conclusions arrived at, and while the writer must be held entirely responsible for all expression of opinion, he wishes to acknowledge his gratitude and indebtedness to Professor Watts and Dr. Evans, both of whom, in numerous discussions, have freely offered suggestions and criticism which have proved to be of the greatest value.

In recent years the chief criteria on which systematic classifications of igneous rocks have been based are (*a*) mineral composition, (*b*) chemical composition, and (*c*) texture, or (*c'*) mode of occurrence (Cross, 1910, p. 473). Although the two latter factors have often been considered interdependent, it is now becoming generally recognized that they are by no means wholly so, and modern custom tends more and more to relegate each of them to a subsidiary position in classification. For the working petrologist, the mineral composition of an igneous rock is, in a great majority of cases, its most important characteristic. Unfortunately, many minerals, such as the pyroxenes and amphiboles, are capable of a wide range in composition. Moreover, a small percentage of igneous rocks are incompletely crystallized. It has therefore to be recognized, and accepted as at present an unavoidable limitation, that the *whole* field of igneous rocks cannot be reliably classified on a mineralogical basis that will also faithfully reflect the chemical composition. On the other hand, a chemical classification, whether founded on normative minerals, or otherwise, demands far more analyses than can in practice be obtained. In addition to the requirements of field-work, it is therefore necessary to have at least two systems of classification, one mineral, the other chemical. Clearly, for purposes of comparison, the two systems should be arranged as closely as possible along parallel lines.

In the Quantitative Classification of Cross, Iddings, Pirsson, and Washington, the chemical composition is expressed, not in oxides, but by a series of standard minerals known as the *norm*, as opposed to the *mode*, which is the actual mineral composition. The first division, into *Classes*, is based on the relative proportions of the *salic* and *femic* groups of minerals in the norm (corresponding terms for the mode are *felsic* and *mafic*). As Mr. G. W. Tyrrell (p. 63) has pointed out, the five classes that are adopted correspond in principle, though in greater detail, to Brögger's division of igneous rocks into leucocratic and melanocratic types.

The second division, into *Orders*, is based in the first three classes on the ratio of quartz, or if quartz be absent of felspathoid, to felspar. The orders thus correspond partially to Professor Shand's division of igneous rocks into oversaturated, saturated, and undersaturated types (1913, p. 513, and 1915, p. 340). One of the most serious defects of the C.I.P.W. Classification, to which attention was drawn by Tyrrell in 1914 (p. 68), lies in the fact that the method of subdivision into orders in Classes IV and V is based on ratios of the femic minerals, thereby introducing a most confusing break and lack of parallelism between the subdivisions of Classes I to III, and those of IV and V. Tyrrell urges that the salic divisions should be carried on through all the classes, and for the same reason the femic divisions of the later classes might, if desired, be carried back through the early classes, thus providing each rock analysed with a double symbol.

It also seems to the present writer that Order 5, embracing as it does rocks with normative quartz and felspar, felspar alone, or felspar and felspathoid, is of too broad a character. It traverses one of the few natural lines of distinction available for classification, the line between the antipathetic minerals quartz and felspathoid. Certainly the norm indicates which of these is present, but in the symbol it might advantageously be expressed by suffixes such as the following:—

5*q* (accessory normative quartz present),
5 (no quartz nor felspathoid present; in this case normative olivine would generally be present),
5*l* (accessory felspathoid, or lenad, present).

The division of orders (of Classes I to III) into *Rangs* is based on the ratio of the molecular proportions of alkalies to lime, only those entering into the salic minerals being employed for comparison. Mineralogically, this is practically the ratio of orthoclase plus albite to anorthite, it being understood that felspathoids, where present, are to be expressed in terms of the amounts of orthoclase and albite to which they are equivalent. The ratio, however, tells us very little about the rock to which it is applied beyond expressing in a general way its alkalic or calcic character. It is suggested below that a more useful method of division would be afforded by the ratio of the molecular proportions of soda to lime in the felspars, or better, of the direct ratio by weight of albite to anorthite. Such a ratio would express the normative soda-lime felspar, and in many cases the latter would not materially differ from the actual soda-lime felspar of the rock.

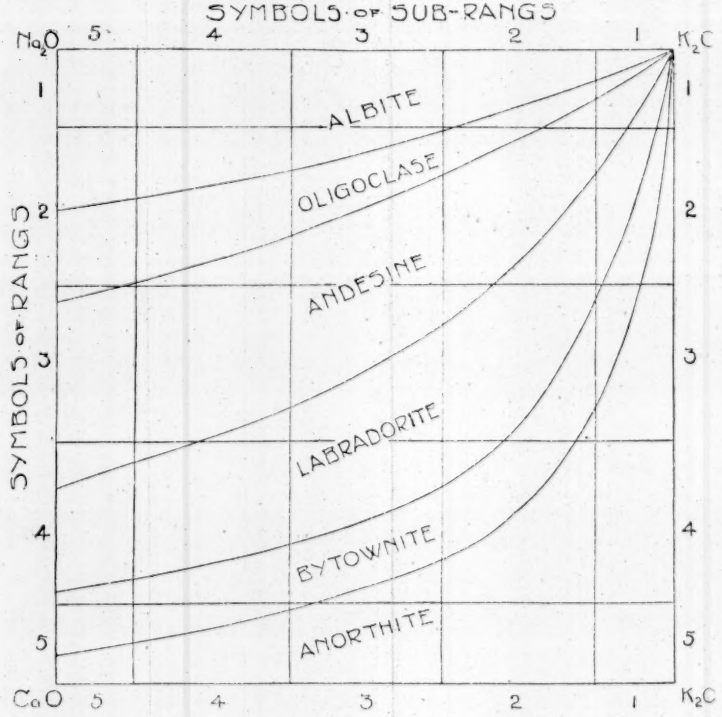
The division of rangs into *Sub-rangs* is based on the molecular ratio of salic potash to salic soda, and is useful in distinguishing rocks with minerals like orthoclase, muscovite, leucite, and biotite, from those containing albite, analcime, nepheline, etc.

It has frequently been a matter for surprise that the sub-rangs of the C.I.P.W. Classification (of which in the first three classes there are 675) do not always contain rocks of closely similar types, and that adjacent sub-rangs may sometimes enclose rocks that are much more closely related to one another than they may be to other rocks falling within their own sub-rang. The latter possibility is illustrated by the following analyses, taken from Iddings' *Igneous Rocks*, vol. ii:—

	A.	B.	C.	D.	E.
SiO_2	75·04	75·17	74·37	73·05	64·57
Al_2O_3	13·12	12·66	13·12	14·67	16·80
Fe_2O_3	2·12	0·23	0·73	0·89	0·97
FeO	n. d.	1·40	0·87	n. d.	3·02
MgO	0·34	0·05	0·35	0·26	1·69
CaO	0·40	0·82	1·26	0·97	3·53
Na_2O	2·44	2·88	2·57	3·99	3·81
K_2O	6·32	5·75	6·09	5·11	4·01
H_2O	0·76	0·82	0·30	0·91	1·28
Incl.	—	0·47	0·45	—	—
Total	100·54	100·26	100·11	99·85	99·68
Symbol :	I, 4, 1, 2 Omeose.	I, 4, 1, 3 Liparose.	I, 4, 2, 3 Toscanose.	I, 4, 2, 3 Toscanose.	I, 4, 2, 3 Toscanose.

A. Felsite porphyry ; Varese, Piedmont.
B. Granitite ; Pikes Peak, Colorado.
C. Granitite ; Crazy Mts., Montana.
D. Obsidian ; Teneriffe, Canary Islands.
E. Toscanite ; Bracciano, Italy.

A, B, and C, falling in adjacent sub-rangs, bear a much closer resemblance to one another than do C, D, and E, all of which fall in the same sub-rang.



In the above diagram the rectangular spaces represent subdivisions of the C.I.P.W. Classification formed by rangs and sub-rangs. The spaces between the curved lines represent the distribution of the different soda-lime felspars across the C.I.P.W. Classification in Classes I–III, Orders 1–4 and part of 5. In the case of other orders, the curves occupy other positions which may be obtained approximately by swinging them upwards about the north-east corner through an angle depending on the amount of felspathoid present in the norm.

Actually, the classification is, as generally used, in four dimensions, and consequently sixteen sub-rangs meet in the theoretical point determined by the intersection of four super-planes. Thus it would be possible for sixteen closely similar analyses to fall into sixteen adjacent pigeonholes, whereas sixteen analyses distributed evenly through any one of the pigeonholes would show considerably more variation. Obviously, this is not a serious fault in the classification unless it can be shown that there is a natural grouping of rocks. If there were, and the existing modal nomenclature is

I.

OVERSATURATED ROCKS: CHARACTERIZED BY QUARTZ.

	Or_0 SODA $Or_{12.5}$ ROCKS.	$Or_{37.5}$ SODA-POTASH ROCKS.	$Or_{62.5}$ POTASH $Or_{87.5}$ ROCKS. Or_{100}
ALBITE.	SODA-GRANITE. Rockallite.	SODA-POTASH GRANITE. Ekerite. Grorudite.	POTASH-GRANITE. Muscovite granite. Muscovite biotite granite.
	PEGMATITE.	PEGMATITE.	PEGMATITE. Granophyre.
	SODA-QUARTZ PORPHYRY	SODA-POTASH Q. PORPHYRY Quartz bostonite. Paisanite.	POTASH QUARTZ PORPHYRY. Aplite.
	SODA RHYOLITE. Comendite and Pantellerite.	SODA-POTASH RHYOLITE.	POTASH RHYOLITE.
An_{15} OLIGOCLASE-ANDESINE.	QUARTZ-DIORITE. Tonalite. / GRANO-DIORITE.	ADAMELLITE. Quartz monzonite.	GRANITE. Biotite-granite. Hornblende granite. Augite granite, etc.
			PEGMATITE. Granophyre.
	QUARTZ PORPHYRITE.		QUARTZ PORPHYRY. Nevadite. Aplite.
	DACITE.	RHYO-DACITE. Quartz latite. Dellenite.	RHYOLITE. Liparite.
An_{50} LABRADORITE-ANORTHITE.	QUARTZ GABBRO. Quartz anorthosite. Quartz norite.	QUARTZ MONZONITE (in part).	Labradorite granite.
	QUARTZ DOLERITE. Quartz diabase.		
	QUARTZ BASALT. Bandaite.	QUARTZ TRACHY-DOLERITE.	
An_{100} Felspar absent or accessory.	QUARTZ PYROXENITE. Quartz hornblendite.		

based on the assumption that there are at least a few such groupings, then instead of fitting them into ready-made compartments the divisions of a satisfactory classification should be drawn around them.

The other feature, to which many criticisms have been directed (e.g. Evans, p. 270; and Harker, *Natural History of Igneous Rocks*, pp. 363–4)—that widely different types of rocks may fall into the same sub-rang—is due partially to the dependence of names on textures, and partially to incorrect applications of the modal nomenclature, much of which, it must be confessed, is unnecessarily vaguely defined. Some glaring examples are exposed in vol. ii of Iddings' *Igneous Rocks*: e.g., "an olivine diabase" with 10·7 per cent normative quartz (p. 144); a "hornblende granite" with 56·8 per cent labradorite and only 7·2 per cent of orthoclase (p. 146); and a "basalt" with 40 per cent of nepheline and leucite and no soda-lime felspar (p. 306).

The relation of the rang classification of soda-lime felspars to those already in use is shown by the following figures, which express the percentage of anorthite in each case.

Soda-lime Felspars.	Tschermak.	Adapted from Day & Allen.	Rang Divisions.	No. of Rang.
Albite	0–11	0–15	0–7	1
Oligoclase . . .	14–33	15–25	7–25	2
Andesine . . .	40–43	25–50	25–47	3
Labradorite . . .	50–67	50–75	47–78	4
Bytownite . . .	75–86	75–85	78–100	5
Anorthite . . .	86–100	85–100		

Another reason for the lack of similarity between the rocks of certain sub-rangs, and one for which the C.I.P.W. Classification is itself wholly responsible, is displayed in the diagram on p. 118. In this, the subdivisions formed by rangs and sub-rangs are drawn to scale, and across them the distribution of the different soda-lime felspars is plotted. In most cases it will be noticed that two or three, and in a few others even more, of the recognized varieties of plagioclase are present within a single compartment. In Toscanose, for example (I, 4, 2, 3), the felspar may be albite, oligoclase, or andesine, and it is precisely this sub-rang to which attention has been directed by Harker (pp. 363–4) as exemplifying the extraordinary degree of non-parallelism between modal and normative classifications. Since in the former the kind of soda-lime felspar is often an important diagnostic, it was an inevitable consequence that the latter, as arranged in its present form (in which the co-ordinates of rang and sub-rang are not independent of each other), should traverse the older nomenclature in an unnatural way. For this reason it is suggested for consideration by the authors of the Quantitative Classification that the molecular ratio of salic alkalies to lime should be replaced by the molecular ratio of felspathic soda to lime. If this were done, each component of the magmatic symbol would convey a definite mineralogical meaning, and rocks having the

II.

SATURATED ROCKS.

Or_0 SODA $Or_{12.5}$ ROCKS. $Or_{37.5}$ SODA-POTASH ROCKS. $Or_{62.5}$ POTASH $Or_{87.5}$ ROCKS. Or_{100}

ALBITE.	SODA AND SODA-POTASH SYENITES. Albitite.		Laurvikite. Nordmarkite. Pulaskite.	POTASH-SYENITE.
	SODA AND SODA-POTASH PORPHYRIES.		Bostonite. Sölvsbergite.	POTASH PORPHYRY. Minette (in part).
	SODA AND SODA-POTASH TRACHYTES. Keratophyre and Pantellerite-trachyte.			POTASH TRACHYTE.
An_{15}				
OLIGOCLASE-ANDESINE.	DIORITE.	SYENO-DIORITE.	MONZONITE.[1] Oligoclase-syenite. Andesine-syenite. Akerite.	SYENITE.
	PORPHYRITE. Malchite.		MONZONITE PORPHYRY. Mænaite.	PORPHYRY.
			Vogesite and minette.	
	ANDESITE.		TRACHY-ANDESITE. Latite. Vulsinite.	TRACHYTE.
An_{50}				
LABRADORITE-ANORTHITE.	GABBRO. Anorthosite. Norite. Hyperite.		LABRADORITE-MONZONITE.	Labradorite syenite.
	DOLERITE. Diabase.		MONZONITE-PORPHYRY. Gauteite.	
	Spessartite and kersantite.			
	BASALT. Tholeiite.		TRACHY-DOLERITE.	
An_{100}				
Felspar absent or accessory.	PYROXENITE. Hornblendite. AUGITITE.			

[1] The name 'Monzonite' as a specific name stands in urgent need of limitation and redefinition. It is given here according to the usage adopted by Brögger, although it should certainly be limited to rocks with a soda-lime felspar at least as calcic as andesine, if not labradorite. The very broad American usage of the term is particularly unfortunate.

same symbol would be much more closely akin than is at present the case. If no normative felspar were present, the rang symbol could be omitted, and the sub-rang symbol would then express the kind of felspathoid in the rock. A fivefold classification of the soda-lime felspars by the rang method would probably be equally as good as the sixfold classification usually adopted.

A natural line of division, similar to that employed to separate quartz-bearing from felspathoid-bearing rocks, may be drawn between quartz-bearing and olivine-bearing rocks.[1] To express the presence of olivine in the norm of a rock the number corresponding to the ratio of pyroxene to olivine (section of grad) might be added to the symbol. As an example of the kind of normative symbol here advocated, the following may be taken: II, 5_l, 4, 4, 1. The characters of the rock could then be read off immediately:—

II	signifies	that salic minerals are dominant;
5_l	,,	,, felspathoid is accessory;
4	,,	,, labradorite is present;
4	,,	,, soda is dominant over potash;
1	,,	,, pyroxene is dominant over olivine.

Clearly the rock would be an olivine-essexite or its equivalent, according to the texture and mode of occurrence.

A purely mineralogical classification, as already pointed out by many petrologists, cannot hope to attain complete parallelism with a normative classification. The mere existence of such alferric minerals as hornblende and pyroxene assures that unfortunate fact. Nevertheless, all the co-ordinates of the C.I.P.W. Classification (with the modification suggested above) are available for a modal classification.

(*a*) The ratio of felsic to mafic minerals is an important characteristic, but certainly not sufficiently so to take first place. If the mineral composition is quantitatively stated, then the ratio is known and may be used for various purposes, such as a subsidiary means of classification, or as a test of rival theories of differentiation. The terms *leucocratic* and *melanocratic* should, in the opinion of the writer, be used without exact quantitative significance, to express variations within a single body of rock, or within a series of associated rocks, relative to the average, or (assumed) parent rock type. For quantitative divisions the modal terms *felsic* and *mafic* are available, and with the C.I.P.W. limits and terminology rocks may be described as perfelsic, M_0–$M_{12\cdot5}$ (using M for mafic constituents with percentage suffixes); dofelsic, $M_{12\cdot5}$–$M_{37\cdot5}$; mafelsic, $M_{37\cdot5}$–$M_{62\cdot5}$; domafic, $M_{62\cdot5}$–$M_{87\cdot5}$; and permafic $M_{87\cdot5}$–M_{100}. (See also Shand, 1916, pp. 400–4.) Tyrrell's suggestion to group the first two of these

[1] The occasional presence in oversaturated rocks of fayalite with tridymite, or other forms of silica, need not invalidate this statement, provided that the term "olivine-bearing rocks" is understood to imply magnesian olivine and to exclude fayalite. The presence of the latter in a rock as a rare accessory does not affect petrographical nomenclature, and as Shand has pointed out, it exists in the company of free silica because an orthorhombic pyroxene of the composition $Fe\,Si\,O_3$ is apparently incapable of a separate existence. (Shand, 1914, pp. 491–2; see also Washington, *Journ. Geol.*, xxii, p. 16, 1914.)

III.

UNDERSATURATED ROCKS: CHARACTERIZED BY OLIVINE.

	Or_0 SODA $Or_{12.5}$ ROCKS.	$Or_{37.5}$ SODA-POTASH ROCKS. $Or_{62.5}$	POTASH $Or_{87.5}$ ROCKS. Or_{100}
ALBITE.	OLIVINE ALKALI-SYENITES. Laurvikite (in part). Rhomb-porphyry (in part). OLIVINE-ALKALI-TRACHYTES. Skomerite. Olivine kenyte.		
An_{15}			
OLIGOCLASE-ANDESINE.	OLIVINE DIORITE. OLIVINE ANDESITE. Mugearite.	OLIVINE MONZONITE [1] (in part?). OLIVINE TRACHY-ANDESITE. Olivine latite.	
An_{50}			
LABRADORITE-ANORTHITE.	OLIVINE GABBRO. Olivine anorthosite. Olivine norite. Olivine hyperite. OLIVINE DOLERITE. Olivine diabase. OLIVINE BASALT.	OLIVINE MONZONITE. Kentallenite. Absarokite. OLIVINE TRACHY-DOLERITE. Ciminite.	
An_{100}			
Felspar absent or accessory.	PICRITE. Olivine pyroxenite. LIMBURGITE. Picrite-basalt.		
Felspar absent.	PERIDOTITE. Wehrlite. Lherzolite. Cortlandite. Dunite.	MICA-PERIDOTITE. Kimberlite.	

[1] See footnote on p. 121.

divisions together as "leucocratic" gives too broad a meaning to the term, for as a rule only perfelsic rocks could accurately—with due respect to their prevalent colour—be described as leucocratic.

(*b*) A much more valuable basis for a primary subdivision of rocks is that recently proposed by Shand (1913, p. 313). In part it corresponds to the orders of the C.I.P.W. Classification and to the vertical divisions of the mineral classification tabulated by Iddings (vol. i, pp. 348–9), but it goes a step further since it contrasts quartz-bearing rocks not only with felspathoid-bearing rocks, but also with rocks characterized by the presence of olivine and of other unsaturated minerals. Shand's contribution to "the framework of a classification" (1915, p. 340), is as follows:—

I. Oversaturated Rocks, which contain free silica of magmatic origin.
II. Saturated Rocks, which contain only saturated minerals (i.e. saturated with regard to silica).
III. Undersaturated Rocks, which contain unsaturated minerals:
  (*a*) Dyad metals undersaturated, e.g. *olivine*-bearing rocks.
  (*b*) Monad metals undersaturated, e.g. *felspathoid*-bearing rocks.
  (*c*) Monad and dyad metals undersaturated, e.g. *felspathoid and olivine* bearing rocks.

In the classification advocated in this paper Shand's five groups are adopted as those of first importance. The principle of saturation is one far superior in its significance to the old conception of igneous rocks as acid, intermediate, basic, and ultrabasic. If the term *acid* means anything at all, as applied to rocks, it suggests the presence of free silica, and quartz-diorites and gabbros should, according to this implication, be classed as "acid rocks". On the other hand, if the term *basic* were logically applied, it would include nepheline-syenites as well as olivine-gabbros.

(*c*) The value of salic or felsic minerals in classification is indicated by the fact that in the norm of Clarke's average igneous rock, the salic minerals amount to 79 per cent of the total (Cross, 1912, p. 759; Tyrrell, p. 69). Moreover, the felspars alone constitute 67 per cent of the total norm. Clarke has also given a modal average of igneous rocks, and according to his figures the felspars constitute practically 60 per cent. The felspars are therefore well adapted for a further division of rocks within each of the five groups separated according to the saturation principle. Since there are three felspar molecules, orthoclase, albite, and anorthite, with albite as a common associate of each of the others, the ratios of albite to anorthite and of orthoclase to albite afford excellent co-ordinates for a cross classification. The writer considers that it is of doubtful value to use the ratio of orthoclase plus albite to anorthite, as is suggested by Tyrrell (p. 79); or that of alkali felspars to soda-lime felspars, as is done by Iddings (*Igneous Rocks*, vol. ii). In the former ratio the kind of soda-lime felspar does not appear in the classification (as in the case of the present method of calculating the rang), and in the latter ratio the terms compared are not independent.

It is proposed in this paper to divide felspathic igneous rocks according to the kind of soda-lime felspar present—the kind being conveniently expressed by the percentage of anorthite. At least

IV.

UNDERSATURATED ROCKS: CHARACTERIZED BY FELSPATHOIDS.

	Or_0 SODA $Or_{12.5}$ ROCKS.	$Or_{37.5}$ SODA-POTASH ROCKS.	$Or_{62.5}$ POTASH $Or_{87.5}$ ROCKS.	Or_{100}
ALBITE.	Mariupolite.	NEPHELINE SYENITE. Laurdalite. Foyaite, Ditroite. Litchfieldite. Covite. Eudialite syenite. Shonkinite. NEPHELINE-SYENITE PORPHYRY. Tinguaite porphyry. Tinguaite. NEPHELINE PHONOLITE.	Borolanite. Leucite syenite. Leucite shonkinite. LEUCITE PHONOLITE.	
An_{15} OLIGOCLASE-ANDESINE.	ESSEXITE (in part).	Shonkinite (in part). Vicoite. Kulaite (in part).	Marosite.	
An_{50} LABRADORITE-ANORTHITE.	THERALITE. Essexite (in part). TESCHENITE. Analcime dolerite.	Nepheline monzonite. Camptonite (in part). LEUCITE TEPHRITE. Kulaite (in part).		
An_{100} Felspar absent or accessory.	NEPHELINE TEPHRITE. Analcime tephrite. IJOLITE. Jacupirangite. Bekinkinite. MONCHIQUITE (olivine free). Fourchite. Nepheline monchiquite NEPHELINITE.	LEUCITE MONCHIQUITE (olivine free). Ouachitite. LEUCITITE.		

three divisions are necessary, those corresponding to albite (up to An_{15}), to oligoclase and andesine (from An_{15} to An_{50}), and to labradorite to anorthite (from An_{50} to An_{100}). Symmetry seems to demand an anorthite division, and in some cases it would be useful to distinguish oligoclase rocks. Probably the five rang divisions of the soda-lime felspars would give somewhat better results, the present objection to using them being merely the lack of an appropriate nomenclature. In particular, the boundary between andesine and labradorite at An_{47} is preferable to that at An_{50}. However, these are extensions of the method which will fall naturally into place as more rocks are quantitatively examined and described.

Secondly, it is proposed to divide the rocks further according to the ratio of orthoclase to albite, or, stating it more generally, according to the molecular ratio of potash to soda. The ratio is conveniently expressed by the percentage of orthoclase in total orthoclase plus albite. In order to give the felspathoid minerals and the micas due weight in the classification, these may also be expressed in terms of the amounts of orthoclase and albite to which they are approximately equivalent. The chief factors required for this conversion are given approximately in the following table:—

ORTHOCLASE	= 1·0	ALBITE	= 1·0
Anorthoclase	= 0·4	Anorthoclase	= 0·6
Leucite	= 1·4	Analcime	= 1·3
Muscovite	= 0·7	Nepheline	= 1·6
Biotite	= 0·6		

Some petrologists may object to the inclusion of biotite as a mineral comparable to orthoclase, but since it may be regarded as containing a leucite-like molecule, it seems desirable to take it into consideration. The writer is aware that at this stage the classification ceases to be purely mineralogical, but it is difficult to avoid some such grouping of minerals if the classification is to be one that can readily be tabulated and memorized. To employ every important mineral as a classificatory co-ordinate would demand more dimensions than can be printed or mentally visualized. The point raised touches the question of the objects of the classification, and these may be stated as follows:—

(*a*) To attain parallelism with a chemical classification as far as possible.

(*b*) To form compartments which shall largely define and limit the types of rocks falling within them.

(*c*) To express the relations of rocks to one another; linear in a chemical and mineralogical sense, and genetic as far as this can be done by a division of space into compartments.

(*d*) To enable students of the subject easily to memorize the ever increasing list of rock names.

(*e*) To indicate to petrologists where new names are necessary, and where they may, with advantage, be avoided.

Returning from this digression to a consideration of the actual subdivisions adopted on a potash to soda basis, we may consider those that have already been used. In the C.I.P.W. Classification the five sub-rangs would give limiting positions at $Or_{12·5}$–$Or_{37·5}$–$Or_{62·5}$–

V.
UNDERSATURATED ROCKS: CHARACTERIZED BY FELSPATHOIDS AND OLIVINE.

	Or_0 Soda $Or_{12.5}$ Rocks.	$Or_{37.5}$ Soda-potash Rocks.	$Or_{62.5}$ Potash $Or_{87.5}$ Rocks.	Or_{100}
Albite.				
An_{15}				
Oligoclase-andesine.	Olivine Essexite (in part).	Olivine shonkinite.		
An_{50}				
Labradorite-anorthite.	Olivine theralite. Olivine essexite (in part). Olivine teschenite. ? Olivine camptonite (in part). Nepheline basanite.	Sommaïte. Leucite basanite. Olivine kulaite.		
An_{100}				
Felspar absent or accessory.	Olivine jacupirangite. Olivine bekinkinite. Olivine monchiquite. Nepheline basalt. Nepheline melilite basalt. Melilite basalt.	Leucite olivine monchiquite. Missourite. Alnoïte. Leucite basalt.		

three divisions are necessary, those corresponding to albite (up to An_{15}), to oligoclase and andesine (from An_{15} to An_{50}), and to labradorite to anorthite (from An_{50} to An_{100}). Symmetry seems to demand an anorthite division, and in some cases it would be useful to distinguish oligoclase rocks. Probably the five rang divisions of the soda-lime felspars would give somewhat better results, the present objection to using them being merely the lack of an appropriate nomenclature. In particular, the boundary between andesine and labradorite at An_{47} is preferable to that at An_{50}. However, these are extensions of the method which will fall naturally into place as more rocks are quantitatively examined and described.

Secondly, it is proposed to divide the rocks further according to the ratio of orthoclase to albite, or, stating it more generally, according to the molecular ratio of potash to soda. The ratio is conveniently expressed by the percentage of orthoclase in total orthoclase plus albite. In order to give the felspathoid minerals and the micas due weight in the classification, these may also be expressed in terms of the amounts of orthoclase and albite to which they are approximately equivalent. The chief factors required for this conversion are given approximately in the following table:—

Orthoclase	= 1·0	Albite	= 1·0
Anorthoclase	= 0·4	Anorthoclase	= 0·6
Leucite	= 1·4	Analcime	= 1·3
Muscovite	= 0·7	Nepheline	= 1·6
Biotite	= 0·6		

Some petrologists may object to the inclusion of biotite as a mineral comparable to orthoclase, but since it may be regarded as containing a leucite-like molecule, it seems desirable to take it into consideration. The writer is aware that at this stage the classification ceases to be purely mineralogical, but it is difficult to avoid some such grouping of minerals if the classification is to be one that can readily be tabulated and memorized. To employ every important mineral as a classificatory co-ordinate would demand more dimensions than can be printed or mentally visualized. The point raised touches the question of the objects of the classification, and these may be stated as follows:—

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(*d*) To enable students of the subject easily to memorize the ever increasing list of rock names.

(*e*) To indicate to petrologists where new names are necessary, and where they may, with advantage, be avoided.

Returning from this digression to a consideration of the actual subdivisions adopted on a potash to soda basis, we may consider those that have already been used. In the C.I.P.W. Classification the five sub-rangs would give limiting positions at $Or_{12·5}$–$Or_{37·5}$–$Or_{62·5}$–

V.
UNDERSATURATED ROCKS: CHARACTERIZED BY FELSPATHOIDS AND OLIVINE.

	Or_0 SODA $Or_{12.5}$ ROCKS.	$Or_{37.5}$ SODA-POTASH ROCKS.	$Or_{62.5}$ POTASH $Or_{87.5}$ ROCKS. Or_{100}
ALBITE.			
An_{15} OLIGOCLASE-ANDESINE.	OLIVINE ESSEXITE (in part).	Olivine shonkinite.	
An_{50} LABRADORITE-ANORTHITE.	OLIVINE THERALITE. Olivine essexite (in part). OLIVINE TESCHENITE. ? Olivine camptonite (in part). NEPHELINE BASANITE.	SOMMAÏTE. LEUCITE BASANITE. Olivine kulaite.	
An_{100} Felspar absent or accessory.	Olivine jacupirangite. Olivine bekinkinite. OLIVINE MONCHIQUITE. NEPELINE BASALT. Nepheline melilite basalt. Melilite basalt.	LEUCITE OLIVINE MONCHIQUITE. Missourite. Alnoïte. LEUCITE BASALT.	

$Or_{87\cdot5}$. Some authors have used 1/3–2/3 (Or_{33}–Or_{67}) as the limiting ratios of orthoclase to total felspar in certain groups of rocks such as monzonite (Hatch, 1916, vol. i, p. 192). This procedure, however, compares orthoclase to soda-lime felspar, and as the composition of the latter varies according to its occurrence in (say) granites or gabbros, adamellites or labradorite-monzonites, it follows that the same factors are not used throughout. Iddings in his modal classification (vol. ii) adopts 3/8–5/8 as limiting ratios, with a still greater possibility of variation in the factors, since for orthoclase he substitutes alkali felspar.

Until we know whether there be a natural grouping of rock types about certain points (and relative abundance of the types concerned must, of course, be the chief test applied), the precise value of the limiting ratios adopted does not seriously matter. Those here employed are the ratios of the C.I.P.W. Classification, using in general only three of the five divisions. The separation of granodiorite from quartz-diorite and adamellite demands a fourth subdivision. According to the definition of Lindgren, the orthoclase limits for granodiorite are about $Or_{10}-Or_{33}$, consequently the C.I.P.W. limits $Or_{12\cdot5}-Or_{37\cdot5}$ will serve equally well. In the other direction, a fifth subdivision is necessary to accommodate the labradorite-monzonites which, starting at $Or_{37\cdot5}$, may be allowed to pass over the $Or_{62\cdot5}$ dividing-line as far as the $Or_{87\cdot5}$ limit. These limits are broader than are actually required, but as they do no violence to the definition of a gabbro, there can be no objection to their adoption. The writer does not wish to insist on rigidly fixed lines of division, for it is his opinion that a really valuable quantitative classification can only emerge when thousands of modes have been measured and statistically examined. The mode is the only "symbol" that can at present usefully be given to a rock. Nevertheless, for a tabular statement to be possible at all, lines must be drawn somewhere, and those adopted seem to enclose all accepted rock names without changing their current significance.

There remain to be considered rocks without actual felspar. Logically, the five divisions here made on successive pages should be repeated for rocks free from felspar, the divisions giving in respective order: Quartz rocks, Pyroxenites and Hornblendites, Peridotites, Felspathoid rocks, and Olivine-felspathoid rocks. It is much more convenient, however, to treat each group as a limiting case of the felspar group to which it most clearly belongs. This is done in the tabulation by placing some of the rocks in question below the corresponding felspathic rocks.

In each division of the tabular scheme, the coarse-grained rocks (generally those of *major intrusions*, to use Dr. Evans' convenient term for 'plutonic' masses) are used as types, and allied porphyritic, fine-grained, or aphanitic varieties (belonging generally to minor intrusions and lava-flows) are grouped with them.

The classification is printed in three dimensions, in sheets superimposed one on another as required. Of these dimensions, the first is based on degree of silica-saturation, and since it involves lines of variation from saturated types in the directions respectively of quartz,

felspathoid, and olivine, it really constitutes a classification on three co-ordinates. To make quantitative divisions the ratios of quartz to felspar, felspathoid to felspar, and of olivine to felspar or mafic minerals, could be employed. In particular it should be pointed out that in the table of oversaturated rocks, quartz-syenites have been squeezed out by the granites, and only consideration for space has deterred the writer from inserting a second sheet to include rocks with small amounts of quartz (on which such rocks as quartz-gabbro would then have properly appeared). The fourth and fifth co-ordinates, printed as second and third dimensions, are quantitative, and depend respectively on the ratios of albite to anorthite (expressed by percentages of anorthite), and of orthoclase (including other potash minerals suitably weighted) to albite (including other felsic soda minerals suitably weighted). A remaining feature, unexpressed in the tables, is the ratio of felsic to mafic minerals. The classification and nomenclature arising from this ratio have already been described; and in practice the ratio constitutes a sixth co-ordinate that may often be of great service as a further means of subdivision. The seventh and last co-ordinate is textural.

Vogt (see Harker, p. 373) has pointed out that in the peridotites the atomic ratio of magnesium to iron gradually increases as the amount of alumina decreases. Dr. Prior has also used the ratio of MgO/FeO with excellent results in a recent and illuminating classification of meteorites (*Min. Mag.*, p. 42, 1916). It may be worthy of notice that in the mineralogical classification of this paper, the same ratio increases from the north-east corner of each sheet to the south-west corner, for rocks having a normal "colour ratio" or felsic/mafic ratio. Indeed, for all such rocks (as far as can be tested by "average" analyses) the chemical variation in any direction is approximately regular.

Glassy rocks are necessarily incapable of treatment, as indeed they must be by any system of classification by minerals. Similarly, most altered rocks, whether they be altered by pneumatolytic or other processes arising from the consolidation of their parent magma, or by weathering processes, must also be excluded. A classification appropriate to express their characters would be based on the processes by which they have been altered, and the mineral and structural changes whereby their new features have been developed.

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REVIEWS.

I.—New Light on the Caledonian Thrust Movements in Norway.

VOL. IV, part i, of the *Norsk Geologisk Tidsskrift*, just published, contains a summary of an exceptionally interesting paper on the tectonics and formation of the Norwegian mountains, read before the Geological Society of Norway by Professor V. M. Goldschmidt, of Christiania University.[1] As the Norwegian and Scottish Highland rocks are of similar age and nature and exhibit the same type of tectonic structure, the discoveries in one region cannot fail to be of interest to the workers in the other: the chief points of the paper are here noticed without any attempt to offer criticism. The main conclusions advanced are of a novel character and have more than a local significance, for the author uses them to elucidate the problems offered by the rocks and structures of other great mountain ranges of the world.

The paper deals with the central Norwegian mountain region in which great masses of eruptive gabbro and granite have been thrust over Ordovician phyllites. A series of arkoses, conglomerates, and schists, known as the "Høifjeldskvarts" (high-mountain quartz) is usually present overlying the phyllites, and an attempt is made to elucidate the hitherto problematical origin and age of the series, to show its relationship to the high mountain eruptives which frequently overlie it, and to demonstrate the conditions under which the Caledonian mountain-building thrust movements obtained. The great difficulty experienced in unravelling the nature and origin of the "Høifjeldskvarts" results from the extreme metamorphism to which a great part of it has been subjected. Thus, if it were possible to classify its green schists and determine their origin, much light would be thrown on many problems, but as yet there is no means of doing this, for a tuff, an agglomerate, a conglomerate, an effusive or intrusive mass may all on alteration give the same kind of amphibolite schist. A district was therefore chosen for investigation in which the regional metamorphism is a minimum, and there are fewest hindrances in the way of an indisputable identification of the rocks. Such a district was found in Central Norway to the east and west of Valdres, north-west from Christiania.

In the first tract discussed, that between Valdres and Gudbrandsdal, the sedimentary origin of the "Høifjeldskvarts" can be established beyond doubt. The series here occupies an extensive area, and

[1] V. M. Goldschmidt, "Om høifjeldskvartsen I og II": *Norsk Geologisk Tidsskrift*, Bd. iv, Hefte i, pp. 44–6, 49–53, Kristiania, 1916.

interbedded in it are conglomerates essentially composed of gabbroid stones. The problem is to determine the relationship of these conglomerates to some adjacent gabbro mountain masses which owe their present position to thrusting. In an early paper Bjørlykke held that the conglomerate was derived from the gabbro, and was thus the younger formation. In a later communication, however, the contrary opinion is expressed that the gabbro is younger than the "Høifjeldskvarts", and was intruded between it and the underlying phyllites. Professor Goldschmidt has made a thorough microscopic investigation of these rocks. The massive gabbro is a very characteristic rock composed of very fresh augite, less fresh biotite, and a wholly decomposed plagioclase; hornblende varieties also occur. The pebbles of the conglomerate exhibit all the varieties of the massive mountain gabbro, from which they are clearly derived. Thus the "Høifjeldskvarts" cannot be older than the mountain-building movements, since these conglomerates were laid down after the gabbro masses had reached their present position. Again, the conglomerate can be followed to places where it is overlaid by the gabbro and has been strongly pressed, often almost out of recognition. Thus the "Høifjeldskvarts" cannot be younger than the thrusting movements, seeing it has been metamorphosed during, and as a result of, their evolution. It is not pre-Caledonian; it is not post-Caledonian; it is Caledonian—a conclusion of great significance, for it shows that the thrusting took place at the earth's surface, a conglomerate being laid down during the process. The gabbro was eroded in front, whilst it was being pushed forward from behind.

The second tract examined lies between Valdres and Hemsedal. Here we have a similar type of structure, only the Ordovician phyllites are overlaid by thrust masses of granite instead of gabbro. In the south of the district the conglomerate beds are seen overlying the granite as a normal basal deposit, with no evidences of pressure action. In the north, on the other hand, the conglomerate has been overridden by the granite, and its pebbles have been pressed and drawn out by the movement. Here also the derivation of much of the conglomerate from the granite which now overlies it is established.

Thus the investigations in both of these districts lead to the conclusion that the sedimentation of the "Høifjeldskvarts" took place whilst the great eruptive masses were being driven forward, and with deposition of material from the erosion of the selfsame masses. By the continuance of the thrusting movements the sediments were covered and metamorphosed. On this interpretation, and in opposition to the orthodox view that the great thrust movements have obtained at a considerable depth, it must be admitted that great mass-thrusting can take place "in daylight" at the surface, so that a mass can be driven forward and be subject to erosion at one and the same time, in such a way as to ride over its own debris. After mentioning the great amount of work which yet remains to be done before all the problems of the "Høifjeldskvarts" can be solved, and the flood of light which a full understanding of this series must throw not only on the formation of the Norwegian mountains but on the general principles of tectonic geology, it is

confidently affirmed that "the old dogma limiting the great thrust movements to a great depth stands no more".

Professor Goldschmidt parallels the Flysch with the "Hoifjeldskvarts" formation. Just as the "Hoifjeldskvarts" is Caledonian, so the Flysch is Alpine in age, being formed contemporaneously with the mountain-building movements, though the petrographical similarity between the two formations is very small, one obtaining its material from forward-thrust eruptives and the other from forward-thrust Mesozoic sediments. In the discussion following the reading of the paper Professor Brøgger expressed his approval of the original views set forth, and the further work of the Norwegian geologists in the light of the new theory will be followed with great interest.

L. Hawkes.

II.—On some Cretaceous Brachiopoda and Mollusca from Angola, Portuguese West Africa. By R. Bullen Newton. Trans. Royal Soc. Edinburgh, vol. li, pt. iii, No. 15, August, 1916.

THE fossils described in this paper were collected by Professor J. W. Gregory and Mr. E. Robins from a cream-coloured limestone in the neighbourhood of Lobito Bay, north of Benguella in Angola. Most of the specimens are poorly preserved, but the author considers that there is sufficient evidence to refer the fauna to the Vraconnian stage, and this view receives support from the Cephalopods which have been examined by Mr. G. C. Crick. Twenty species are described, of which only seven are definitely identified with forms already known, and two are described as new. Twelve of the species are either identified or compared with European forms. The 'Brazilian facies' of the fauna mentioned by the author seems to depend mainly on some resemblance between *Akera Gregoryi* and *A. Browni*, since the other species common to Angola and Brazil are widely distributed forms.

The species recorded by Mr. Newton are: *Terebratula depressa*, Lam., *Exogyra* cf. *flabellata*, Goldf., *Neithea æquicostata*, Lam., *N. angoliensis*, sp. nov., *N. quadricostata*, Sow., *N. tricostata*, Coq., *Lima* cf. *iteriana*, P. & C., *Volsella* sp., *Trigonarca* cf. *ligeriensis*, d'Orb., *T.* cf. *diceras*, Sեg., *Trigonia crenulata*, Lam., *Anthonya* cf. *Baudeti*, Coq., *Trachycardium* cf. *syriacum*, Coիr., *Panopæa* cf. *plicata*, Sow., *Pholadomya* cf. *Vignesi*, Lart., *Toucasia* sp., *Tylostoma globosum*, Sharpe, *Hipponyx* sp., *Akera Gregoryi*, sp. nov.

III.—Illinois Fossil Invertebrates.

1. *Atactocrinus*, a new Crinoid genus from the Richmond of Illinois (pp. 239–41, pl. xv).
2. Description of a Ste. Genevieve Limestone Fauna from Monroe County, Illinois (pp. 243–65, pls. xvi–xix).

By Stuart Weller. Being Contributions from Walker Museum, vol. i, No. 10. University of Chicago, April, 1916. Price 1*s.* net.

WHAT the Walker Museum may previously have contributed seems generally unknown in this country, but if the isolated part that has reached the review-office of the Geological Magazine be a fair sample we should be glad to see more.

1. The genus *Atactocrinus*, here carefully described, is regarded as a Dicyclic Camerate crinoid of which only the following plates are known : 5 infrabasals, 5 basals, 5 radials, 5 primibrachs, and 5 interradials, each of the last supporting 2 interbrachials. Its peculiarity is that two adjoining interradii and a third opposite to them separate the adjacent radials, whereas across the two remaining interradii the radials meet; consequently three of the basals are truncate above, while the other two are pointed. Thus the cup is bilaterally symmetrical in its irregularity.

Dr. Weller regards the genus as intermediate between the Dimerocrinidae and the Rhodocrinidae, and says that "if the two antero-laterals [basals] were pointed it could be . . . placed in the Dimerocrinidae". In that Family, however, the posterior interradial supports three plates, not two as here and as frequently in the Rhodocrinidae. The last-mentioned Family comprises a genus in which the lower part of the cup is composed of the same number of plates having the same general arrangement, namely *Lyriocrinus*. In that genus, as Wachsmuth & Springer have pointed out, the basals may be all truncate above or "quite frequently one or more of them hexagonal, and angular at the top". Why then is Dr. Weller's specimen not a *Lyriocrinus* with two basals in the latter condition? In the portion preserved the only points of difference from Wachsmuth and Springer's diagnosis are the slightly greater prominence of the infrabasals, correlated with the less depression of the lower part of the cup. This is consistent with its lower horizon, at the top of the Ordovician, previously known species being Middle Silurian. The ornament differs from that of the other American species, but is of the same general nature as that seen in some examples from the Wenlock Limestone (Brit. Mus., E 14697, E 15617). The assigned columnals are higher and more bead-like than usual in the genus, but in the Wenlock specimen (Brit. Mus. E 7095) the most distal of the columnals preserved approach this shape.

2. The Sainte Genevieve Limestone, of Middle Carboniferous age, lies between the Kaskaskia and the St. Louis Limestone, with which latter it was till recently confused. To help towards the distinguishing of its fauna, the second paper describes a collection from a single locality and bed. It makes known 26 new species of Lamellibranchs and Gastropods. All species, old as well as new, are illustrated by half-tone reproductions of photographs, enlarged two or four diameters. The results are no more beautiful than are usual with this process; it is to be hoped they may prove more useful.

It is not stated that the specimens described in these two papers are preserved in the Walker Museum of Chicago University.

F. A. Bather.

IV.—The Structure and History of Plav: the Floating Fen of the Delta of the Danube. By Marietta Pallis. Journal of the Linnæan Society, vol. xliii, pp. 233–90, 1916.

PLAV is the name given to the floating reed fen which is found in the Balta or marsh district in the delta of the Danube. It is chiefly composed of the interlacing vertical rhizomes of the giant

reed, *Phragmites communis*, Trin., *β. flavescens*, Gren & Godr. These, with the soil which they retain by the aid of their roots, form a subaqueous mass about 6 feet in thickness. This can be divided into three layers: the uppermost, about 6 inches thick, with a very highly organic black soil in which are rooted various water plants; the middle, about 18 inches thick, with a lighter soil containing 40 per cent of organic matter; and the lowest, about 4 feet thick, with a soil having an organic content of only 17 per cent. From these rhizomes grow reed shoots as high as 17 feet, which form the aerial portion of the Plav.

The formation of Plav takes the following course: first round the sandbanks an "open reed swamp" forms (i.e. a swamp in which the reeds are fairly widely separated from one another). This in course of time by the spreading of the reeds becomes thicker, forming a "closed reed swamp". This swamp then begins to lose its hold on the ooze in which it is rooted by the death of some of the lower rhizomes; if then the water is not shallow enough for the mass of rhizomes to fill it entirely to the surface, the hydrostatic pressure on the upper layers will cause the mass to rise, and it will become floating reed swamp or Plav. The three necessary conditions then for the formation of Plav are: that the water should be sufficiently deep; that the floods do not bring down much silt which would lessen the depth of the water so that the lower rhizomes could become re-rooted; and that the basal decomposition should set in in the swamp stage and not in the fen stage, as happens in Norfolk, where the reeds fill up the whole water space before basal decomposition sets in.

Some Plavs are miles long, and are attached at one side or end; others, however, are quite small and form floating islands. These latter may be broken pieces of the larger Plavs, but more probably originated on a small bank so that they became free floating when detached at the base. To what extent Plav may be regarded as another substance for coal is not very clear. The large amount of inorganic soil it contains would indicate a higher ash content than is usual in most coals. If, however, the delta of the Danube were invaded at some early date by the sea something very much resembling coal would, no doubt, be found there.

W. H. W.

V.—Geological Notes, Northern Territory, Australia. By E. J. Dunn. Proc. Roy. Soc. Victoria, vol. xxviii (n.s.), pt. i, pp. 112–14.

IN this publication Mr. E. J. Dunn describes a portion of the core of a borehole, where the appearance of highly contorted strata has been produced in rocks of Carboniferous age by the boring of worms. The worms made tortuous holes in black mud at a time when white sand was being deposited. This washed into the holes and filled them up, giving the appearance of a high degree of contortion.

He also describes how the formation of rounded pebbles may take place without the wearing action of water. At the mouth of the

Victoria River large numbers of fragments of quartzite are found just above high-water mark. These in time are changed from angular fragments to rounded pebbles with a rough surface. This seems to be caused by the continual wetting of the stones with sea-water, followed by crystallization of the contained salts by the heat of the tropical sun. It is not certain whether the action is a chemical or a physical one, or whether it is a mixture of the two; but the result seems to be that the secondary quartz cement is removed, leaving the primary quartz grains standing up to form a roughened surface.

W. H. W.

VI.—Brief Notices.

1.—Detrital Andalusite in Cretaceous and Eocene Sands. By G. M. Davies, B.Sc., F.G.S. Min. Mag., vol. xvii, No. 81, pp. 218–220, 1915.

IN this short paper Mr. G. M. Davies records the occurrence of unaltered pleochroic andalusite in many Eocene sands of the London district, in the Lower Greensand of Reigate, Limpsfield, and Folkestone, and even in the Wealden beds of Spotover Hill near Oxford. He mentions also that the mineral has been observed in the St. Bees Sandstone, of Triassic age. These observations will serve to reverse the opinion formerly held that, owing to its instability, andalusite would not be found in strata older than the Pliocene.

W. H. W.

2.—Fauna of the Fernando of Los Angeles. By Clarence L. Moody. University of California Publications, Bulletin of the Department of Geology, vol. x, No. 4, pp. 39–62, pls. i–ii, 1916.

THE fauna referred to in this memoir consists mainly of mollusca, of which there are stated to be 147 species, only about ten species being represented of other groups such as the Echinoidea, Brachiopoda, Bryozoa, etc. The following new species are described and figured: **Gastropoda**, *Siphonalia gilberti*, *Chrysodomus dirus meridiei*, var. nov., *Trophon raymondi*, *Columbella* (*Astyris*) *constantia*, *Turris* (*Drillia*) *modestus*, *Borsonia inculta*, *Mangilia muricidea*, *Cancellaria quadrata*; **Pelecypoda**, *Pecten* (*Propeamussium*) *levis*, *Macrocallista densa*, *Corbula tenuis*. The author regards the fauna as presenting a boreal aspect, and nearly similar to that characterizing the San Pedro Pliocene beds of California, which has been described by Dr. Ralph Arnold, and which belongs to the lower horizons of the San Diego formation.

R. B. N.

3.—Some American Fossil Insects. By T. D. A. Cockerell. Proc. United States Nat. Mus., vol. li, pp. 89–106, pl. ii, No. 2146, 1916.

THE specimens described in this paper range in time from the Coal-measures to the Miocene, while the author's studies of their structures have enabled him to recognize certain new genera as well as new species which may be listed as follows—**Diptera**: *Plecia woodruffi* from the Green River Eocene beds of Utah, *Psilocephala*

scudderi, *Oxycera rohweri*, *Empis perdita*, *Protolomatia recurrens*, *Protepacmus* (nov. gen.) *setosus*, *Pachysomites* (nov. gen.) *inermis*, *Tabanus merychippi*, *Chilosia sepultula*, *Sciara florissantensis*, *Cordylura exhumata*, *Chironomus scudderiellus*, from the Miocene Shales of Florissant. **Lepidoptera**: *Tortrix* (?) *destructus*, from the Florissant Miocene. **Trichoptera**: *Dolophilus* (?) *præmissus*, Upper Cretaceous (Emscherian) of Tennessee. **Protorthoptera**: *Danielsiella* (nov. gen.) *priscula*, Carboniferous of Illinois. **Odonata**: *Lithragion* (?) *optimum*, Miocene of Florissant. **Hymenoptera**: *Aulacites* (nov. gen.) *secundus*, *Eriocampoides micrarche*, Miocene of Florissant. **Coleoptera**: *Saperda lesquereuxi*, Miocene of Florissant, *Calandrites hindsi*, *Ophryastites hendersoni*, from the Eocene of North Park, Colorado.

4.—Alexandrian Rocks of the North-Eastern Illinois and Eastern Wisconsin. By T. E. Savage. Bulletin of the Geological Society of America, vol. xxvii, pp. 305–24, pls. xv–xvii, 1916.

THE author's investigations on this subject lead him to recognize that a correlation exists between the Mayville Beds of Wisconsin and the Alexandrian rocks of North-Eastern Illinois, as also between the Alexandrian rocks of the Mississippi Valley and the early Silurian strata of Anticosti. The fossils figured and described from the Alexandrian rocks belong to the Brachiopoda; there is besides a form of *Eurypterus* (*E. pumilus*, n.sp.). Some new species or varieties among the Brachiopods are referred to the genera *Schuchertella*, *Clorinda*, *Stricklandinia*, *Platymerella*, and *Virgiana*.

5.—The Glossopteris Beds of Northern Queensland.

The Glossopteris Beds of Betts's Creek, Northern Queensland. By J. H. Reid, A.S.T.C., Fifth Government Geologist, Geological Survey of Queensland. Publication No. 254. pp. 21, with two plates (maps) and four text-figures (sections and map). With an Introductory Note by B. Dunstan, Chief Government Geologist, 1916.

THIS is an important contribution to the geology of Queensland, the beds in question at Betts's Creek having long been recognized as containing *Glossopteris* remains, although assigned by W. H. Rands to a Cretaceous age and claimed as forming part of the Desert Sandstone series. The author regards the deposits as of Permo-Carboniferous or probably of Upper Coal-measure age, mentioning that they are overlain by "Desert Sandstone" and divided by a slight unconformity. A list of the flora referred to includes *Glossopteris browniana* (Brongniart), *Vertebraria*, *Phyllotheca*, etc.

6.—New Brachiopods of the genus *Spirifer* from the Silurian of Maine. By Henry Shaler Williams. Proc. United States National Museum, vol. li, pp. 73–80, pl. i, No. 2144, 1916.

THE species described in this pamphlet are said to exhibit a closer relationship to the Wenlock–Ludlow formations of Great Britain than to the Niagara of the interior of the American Continent. They

were obtained from the Edmunds formation of Washington County, Maine, and include: *Spirifer* (? *Delthyris*) *trescotti*, *S. cobscooki*, *S. edmundsi*, *S.* (cf. *Cyrtina*) *lubecensis*.

REPORTS AND PROCEEDINGS.

I.—Liverpool Geological Society.

January 9, 1917.—J. H. Milton, F.G.S., F.L.S., President, in the Chair.

The following paper was read:—

"The Millstone Grit of Yorkshire." By Albert Gilligan, B.Sc., F.G.S.

The petrography of this great series of rocks has been almost entirely neglected since the classic work of Dr. Sorby, carried out in the middle of last century. From the evidence of the pebbles found in the grit beds, Sorby concluded that the material making up the series had been derived from a landmass having the same lithological characters as the Scandinavian Peninsula, which probably formed an extension of that peninsula to the south-west.

For many years Mr. Gilligan has been engaged in examining not only the pebbles but also the general material making up the series, and has further made a study of the heavy minerals of a large number of the beds. Among the larger pebbles have been found quartz and felspar porphyries, granites of various types, gneisses, schists, sandstones, and mudstones. The source of some of these can be traced to Scotland, while one of them so much resembles the well-known rhomb-porphyry of the Christiania region as to suggest that it represents one of the facies of that rock. Quartz pebbles are abundant in all the coarser beds, and these invariably show the effects of pressure, many presenting a mylonized structure. The pink felspar pebbles are always exceedingly fresh, and in nearly all cases are found to be microcline or microcline-microperthite. Pieces of pegmatite, the constituents being quartz and microcline, are common in all the beds, but most abundant in the Kinder Scout and Rough Rock. A few small pebbles of great rarity show oolitic structure, while others contain traces of organisms such as sponge spicules, etc. Chert pebbles differing from those specimens which have been examined from the underlying Carboniferous beds have been obtained from the coarse beds.

The heavy minerals are very irregularly distributed, some layers being extremely rich, while an adjacent bed will yield but a small number. They include the following: ilmenite, magnetite, garnet, zircon, rutile, tourmaline (blue and brown), anatase, and monazite. This last mineral is of great interest, and was first found in the garnetiferous layers of the Rough Rock, and has since been discovered in the basement grit of Pen-y-gent and the Middle Grits of the Aire Valley.

The Millstone Grit shows such striking resemblances to the Torridon Sandstone that Mr. Gilligan is disposed to think that they were in great part derived from a common source.

The paper was illustrated by specimens and by a beautiful series of lantern slides of scenery and photomicrographs.

II.—Geological Society of London.

1. *January* 24, 1917.—Dr. Alfred Harker, F.R.S., President, in the Chair.

Dr. Aubrey Strahan, F.R.S., Director of H.M. Geological Survey, addressing the President and Fellows, said that in 1914 a proposal was made to subscribe for a bust of Sir Archibald Geikie which would be presented to the Board of Education for preservation in the Museum of Practical Geology. Notwithstanding that war broke out shortly after the scheme was launched, the proposal was warmly supported by geologists at home and abroad, and among others by Fellows of the Society. A marble bust, executed by Professor E. Lantéri, of the Royal College of Art, was presented to the Board on March 14, 1916, and placed in the Museum. At the same time a replica was presented to Sir Archibald, who has since made it a gift to the University of Edinburgh, where he was the first Murchison Professor. The past and present staff of the Geological Survey and Museum, thinking that a copy of the original model of the bust would be a suitable gift to the Geological Society of London, in whose affairs Sir Archibald had taken so prominent a part, had caused a cast to be made, and Dr. Strahan, on their behalf, offered it for the acceptance of the Society.

The President, referring to Sir Archibald Geikie's long and intimate connexion with the Society, gratefully accepted the gift on behalf of the Fellows.

Mr. Scoresby Routledge, M.A., gave an account of Easter Island. He said that the expedition that he had had the honour to command was organized with the object of carrying out a long-standing wish of various bodies interested in anthropology. This wish was that Easter Island, and other islands most near to it, though far distant from it, should be thoroughly examined, and that all information and material thereon found should be carefully considered on the spot, or, if possible, be brought back for comparative study.

This programme necessitated a vessel being specially designed, built, and equipped for the purpose. A schooner with auxiliary motor power, the *Mana*, of 90 tons gross register, 78 feet on the water-line, 20 feet beam, and drawing 10·5 feet aft, was accordingly completed by the end of 1912, and she sailed from Southampton in February, 1913, with a company of twelve all told, of whom four formed the scientific staff. After the longest voyage ever made by a yacht under canvas, she sailed into Southampton again in June, 1916, without having experienced accident to man or material.

The course taken was through the Magellan Straits, and thence through the labyrinth of Andean waterways that stretch north therefrom, and are known as the Patagonian Channels.

On reaching Juan Fernandez Island, the *Mana* had to put back to Valparaiso because the geologist of the expedition, the late Mr. F. L. Corry, had contracted typhoid fever on the Chilean coast. Mr. Corry never recovered sufficiently to allow him to rejoin the expedition. Hence no formal geological report on the island could be submitted to the meeting. It was thought best, therefore, to endeavour to convey the conditions existent on Easter Island by means of a series of panoramic and other photographs, specially taken

to illustrate geological features. As these very largely consist of coast-sections, the opportunity was taken to show, and explain, other pictures that were closely associated with them. Such were the ruins of the village called Orongo, consisting of peculiar canoe-shaped houses built of imbricated slabs of shale, with the roof convex, both longitudinally and transversely, on its exterior aspect, and covered with earth. They are romantically situated on the rim of the volcano of Rano Kao, with an almost sheer drop of 900 feet into the sea, or of 600 feet into the crater-lake. At Orongo, too, are found certain large rocks, carved with the symbol of a bird-headed man, holding in its hand an egg. A cult, based on annually obtaining the first-laid egg of a certain migratory sea-bird, was thus gradually brought to light, and appears to be a unique form. A brief outline only could be given of some of the knowledge obtained concerning the peculiar routine associated with seeking, and taking, the sacred egg, and of the part which it occupied in the former religious life of the island.

Proceeding along the coast, typical examples of the great terraces, and their giant stone figures, were shown, and their leading characteristics discussed. A submarine freshwater spring, near the great image-terrace of Tongariki, and opposite certain typical lava-formed caves, gave occasion to the lecturer to explain how had arisen the longstanding and worldwide spread report that man and beast on Easter Island habitually drink sea-water in the place of fresh.

The old volcano of Rano Raraku, the centre of the former religious life of the island, was then described. A series of panoramic pictures, preceded by an accurate survey made by Lieut. R. D. Ritchie, R.N., the cartographer of the expedition, showed a crater-lake surrounded by a rim of tuff which rises to a height of 540 feet above the surrounding plain. The plain is undulating in surface, formed superficially of hard, dense, but nevertheless vesicular lava, and it rests on compact non-columnar basalt. One section of this crater wall, some 600 yards long, on both its interior and exterior aspects, was seen to be quarried right up to the highest point. On the mountain face, both inside and out, large numbers of statues, in every state of completion, were to be seen. The largest of these measured 68 feet in length. Some of those excavated by the expedition exhibited fine details, such as the finger-nails, in perfect condition.

In conclusion, Easter Island might be described as a plateau of basalt raised from 50 to 100 feet above the sea. Superimposed on this were numerous cones ranging up to nearly 2,000 feet. The plateau was covered but sparsely with soil, and could only be crossed with difficulty in any direct line. The cones, on the other hand, were generally smooth of surface, with a good depth of soil. Nevertheless the island is practically without trees, bushes, or shrubs.

A short discussion followed, to which the Lecturer replied; and the cordial thanks of the meeting were accorded to Mr. Routledge for his lecture.

A large series of lantern-slides and specimens of the rock of which the stone images of Easter Island were made were exhibited by Mr. Scoresby Routledge, M.A.

Mr. J. B. Scrivenor, M.A., F.G.S., Government Geologist to the Federated Malay States, exhibited a manuscript geological map of the Malay States. This

map, which he presented to the Society, was prepared by himself from all sources, and represented all that was known of the geology of the region at the end of the year 1916.

Anniversary Meeting.

2. *February* 16, 1917.—Dr. Alfred Harker, F.R.S., President, in the Chair.

The following extract is taken from the Report of the Council for 1916:—

Awards and Medals.

The fourteenth Award from the Daniel Pidgeon Trust Fund was made on April 5, 1916, to John Kaye Charlesworth, M.Sc., Ph.D., who proposed to conduct researches in connexion with the Glaciation of Donegal.

The following Awards of Medals and Funds have also been made:—

The Wollaston Medal is awarded to Professor Antoine François Alfred Lacroix, in recognition of his "researches concerning the Mineral Structure of the Earth", especially in connexion with the Mineralogy and Petrology of France and her Colonies.

The Murchison Medal, together with a sum of ten guineas from the Murchison Geological Fund, is awarded to Dr. George Frederic Matthew, as an acknowledgment of his valuable work on the Stratigraphy and Palæontology of the Lower Palæozoic Rocks of North America.

The Lyell Medal, together with a sum of twenty pounds, is awarded to Dr. Wheelton Hind, as an acknowledgment of the value of his contributions to the Geology of the Carboniferous Rocks of Britain, and of his researches on the Palæozoic Lamellibranchia.

The Bigsby Medal is awarded to Mr. Robert George Carruthers, as a mark of appreciation of his work on the Carboniferous Anthozoa and of his contributions to Scottish Geology, and to stimulate him to further research.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Dr. Percy George Hamnall Boswell, in recognition of his investigations on the Tertiary and Quaternary Deposits of East Anglia, and on the Petrology of the Sedimentary Rocks.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Dr. William Mackie, as an acknowledgment of his valuable work on the Sedimentary and Igneous Rocks of Scotland, especially in connexion with his researches on the Petrology and Palæontology of the Old Red Sandstone of Elgin.

A moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Dr. Arthur Hubert Cox, in recognition of the value of his contributions to the Stratigraphy of the Lower Palæozoic Rocks of South and Central Wales.

A second moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Tressilian Charles Nicholas, as an acknowledgment of his work on the Stratigraphy and Palæontology of the Lower Palæozoic Rocks of North Wales.

The Balance of the Proceeds of the Barlow-Jameson Fund is awarded to Mr. Henry Dewey, in recognition of his contributions to the Geology of the South-West of England and of his researches in connexion with Quaternary Deposits.

III.—Mineralogical Society.

January 16, 1917.—W. Barlow, F.R.S., President, in the Chair.

A. Holmes and Dr. H. F. Harwood: The Basalts of Iceland, Faroe Islands, and Jan Mayen. The basalts described fall into four well-marked types based on the presence or absence of olivine and the porphyritic or non-porphyritic character of the structure. They resemble the Greenland basalts previously described by the authors, and the whole series is closely matched by the basalts of Skye and County Antrim. Chemically the most striking feature of the lavas is their high content of titanium dioxide, which in the seven analyses made varies from 2·36 to 5·68 per cent. The olivine-free rocks are remarkable for their abundance of titaniferous magnetite. In the olivine basalts this mineral is less abundant, and much of the titanium is presumably in the pyroxene, which in the olivine varieties only is of a purple-brown tint. A peculiarity of the olivine basalts is their comparative richness in alkalies, a feature that brings them into relationship with the titaniferous-olivine basalts of the Western Mediterranean described and analysed by Washington. The Arctic province, however, is distinguished by the abundance of alkali-poor basalts, which in spite of the fact that their silica percentages are low are thoroughly over-saturated rocks.

Professor H. Hilton: On the use of the Orthographic Projection in Crystallography. The method of preparing a projection and its use in the drawing of crystals were explained, and the advantages of this projection of the sphere were pointed out.

J. V. Samojloff: Palæophysiology, the Organic Origin of some Minerals occurring in Sedimentary Rocks. In connexion with the exploration of the phosphate deposits of Russia, the occurrence of barytes has been noted over a wide area in the governments of Kostroma, Kazan, and Simbirsk, and also further to the north-east in the basin of the Pechora River. The mineral occurs as nodules in the clays and marls of the Upper Jurassic, and is confined to the Oxfordian–Sequanian horizon, though extending up to the Kimmeridgian in some of the districts. Nodules of barytes have been dredged from the sea-floor off the coast of Ceylon, and granules of barium sulphate have been detected in the bodies of certain marine organisms, namely the Xenophyophora. If, therefore, during the Upper Jurassic period such organisms, capable of extracting barium salts from sea-water, were more abundant, they would account for the accumulation of barium in these strata, where the barytes occur as a primary mineral. Similarly, the mineral celestite has been found over a very wide area in Turkestan in beds of Upper Cretaceous age. The presence of strontium sulphate has been detected in the skeletons of the Acantharia, a group of the Radiolaria. It is conceivable that

similar organisms were relatively more abundant during the Cretaceous period, and that their remains gave rise to the deposits of celestite. Although the iron compound hæmoglobin plays an important function in the blood of present-day animals, yet cases are known amongst the Crustacea and Mollusca in which the copper compound hæmocyanin performs the same function, and vanadium has been detected in the blood of the Ascidia. During former periods of the earth's history these, and perhaps some other, metals may have been predominant in the blood of animals then living. In this connexion the persistent occurrence in the Permian strata of copper minerals and ores associated with abundant animal remains is significant. Similarly, there may have been at different periods variations in the chemical composition of the ash of plants. The recurring presence of minerals of primary origin in certain sedimentary strata therefore suggests that there may have been varying physiological processes during past periods, and for this new branch of palæontology the name "Palæophysiology" is suggested.

E. S. Simpson: On Tapiolite in the Pilbara Gold-field, Western Australia. The mineral, which was discovered at Tabba-Tabba Creek and Greens Well, lying in a large area of granite intersected by pegmatite veins and greenstone dykes and bosses, occurs in fairly well-defined crystals, which analysis proved to contain little niobium. At the first locality the crystals displayed the forms 100, 001, 111, 101, 320, and were twinned as usual on 101 and often distorted; while at the second they displayed the forms 100, 111, 101, 320, and showed twinning about 106 and 301 as well as 101. A curve was prepared showing the specific gravity obtaining in the tetragonal isomorphous series of metatantalates and metaniobates of iron, manganese, and calcium.

IV.—Edinburgh Geological Society.

January 17, 1917.—Dr. Flett, F.R.S., President, in the Chair.

1. "Low-level Kettle-holes in and near Aberdeen." By Dr. Alexander Bremner.

A number of kettle-holes, i.e. cup-shaped hollows due to the melting out of isolated masses of ice embedded in fluvio-glacial and morainic deposits, occur below the 100 ft. contour-line in the Aberdeen district. During marine submergence such hollows could not fail to be obliterated by wave action. Hence it may be inferred that in this district (1) there was no 100 ft. submergence, or (2) the submergence was anterior to or contemporary with the last advance of the local ice.

2. "The Glacial Geology of the Stonehaven District." By Dr. Bremner.

The district dealt with extends westward from the coast between Dunnottar Castle and Portlethen village to the Dee watershed and south-westward to the Bervie Water from Drumlithie upward. A description was given of the traces left by the ice which, in a phase

of the Ice Age succeeding the maximum glaciation, flowed north-east from Strathmore (Strathmore Ice), and of those left by the ice which, after the final or partial disappearance of the Strathmore Ice from the district, passed over the Dee watershed and brought with it a characteristic "granite drift" (Dee Valley Ice). Striation (E. 32° S.) due to the latter ice was recorded from Belteraig, near Portlethen. Many peculiar valleys (glacial overflow channels) were noticed, the largest being the gorge through which the Caledonian Railway runs for fully a third of the distance between Drumlithie and Stonehaven Stations.

It was pointed out that at Stonehaven, as at Aberdeen, no beach deposits referable to the 100 ft. submergence have ever been observed, but that there is strong evidence in favour of the existence of a pre-glacial rock platform (now overlaid by glacial deposits) at a level of 75 to 100 feet above O.D.

3. "Notes on River Development in the East-Central Highlands." By Dr. Bremner.

Many instances of rearrangement of drainage in the East-Central Highlands were noted, and it was proved that in Sheets 64 and 65 there occurs no authentic case of recent (post-glacial) river capture; in particular, capture of the Slugain by the Quoich was shown to be pre-glacial. (See also *Scottish Geographical Magazine* for November, 1915.)

The complicated history of the River Muick was traced in some detail. By successive captures, its headwaters (Allt an Dubh Loch) have been diverted from their original course down Glen Mark so as to enter the Dee (1) by way of the Girnock Burn and the wind-gap west of the Coyles of Muick, (2) by way of the present lower Muick.

The dismemberment of the original Tarf (Sheet 64) by the Bruar, Tromie, and Edendon, and possibly by the Mhaire, was also discussed.

CORRESPONDENCE.

FORAMINIFERAL LIMESTONES FROM NEW GUINEA.

Sir,—When reviewing the literature on some Foraminiferal limestones from New Guinea, during the preparation of a paper published in May last as No. 20 of a series of "Reports on the Collections made by the British Ornithologists' Union Expedition and the Wollaston Expedition in Dutch New Guinea, 1910-13", issued in 1916, I regret having overlooked an important contribution to the subject by my friend Mr. Frederick Chapman, the palæontologist of the National Museum at Melbourne, entitled "Description of a Limestone of Lower Miocene Age from Bootless Inlet, Papua" (Journ. Proc. Roy. Soc. New South Wales, vol. xlviii, pp. 281–301, pls. vii–ix, 1914–15). The forms of Foraminifera referred to by Mr. Chapman are almost identical with those mentioned in my report as occurring in the limestones of Mount Carstensz, and, moreover, the stratigraphical results are exactly similar in each case. It is